AFFTC-TIM-05-02

LIMITED CHARACTERIZATION OF THE SPADS RADAR SYSTEM

Project "START"

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JUNE 2005

FINAL TECHNICAL INFORMATION MEMORANDUM

Approved for public release; distribution is unlimited.

**AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
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UNITED STATES AIR FORCE**

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14. ABSTRACT
The USAF Test Pilot School conducted flight tests to characterize the Weibel-manufactured Spaceport Arrival and Departure System (SPADS) radar functionality and performance for potential use as a single-station time-space-position information (TSPI) source. TSPI truth source data was measured with Advanced Range Data System (ARDS) pods for aircraft tracking, cinetheodolites for munition trajectory tracking and video bomb scoring (VBS) for bomb impact predictions.

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EXECUTIVE SUMMARY

The USAF Test Pilot School (TPS) Spaceport Arrival and Departure System (SPADS) Test Aircraft & Range Tracking (START) Test Team performed a characterization of the SPADS radar. The overall test objective was to characterize the SPADS radar system in terms of functionality and performance for potential use as a single-station time-space-position information (TSPI) source. All test objectives were met.

Testing was requested by the Range Division of the Air Force Flight Test Center (AFFTC/ENR), Edwards AFB, California. Testing was conducted at Edwards AFB, California from 6 April to 4 May 2005. Seven test flights were flown for a total of 7.2 flight hours. The AFFTC job order number (JON) was M05C6000. Chase aircraft, paid for from the USAF Test Pilot School JON (M94C1400), were used in each test flight.

The SPADS system was a mobile multi-frequency continuous-wave (MFCW) radar, made by Weibel and mounted onto a Kineto Tracking Mount (KTM). The radar operated in the X-band with adjustable frequencies from 10.40 to 10.55 gigahertz. The antenna had a gain of 37 decibels and operated with variable beam widths from 2.5 by 2.5 degrees to 10 by 10 degrees with an average output power of 160 watts.

The test included object tracking compared to various truth sources. Aircraft tracking was compared to advanced range data system (ARDS) pod data. The TSPI errors were predominantly within one ship width and were the greatest when optical tracking by the human operator was the most difficult. Munition trajectory tracking was compared with cinetheodolite data. For BDU-50 inert munitions, the median TSPI errors were approximately one bomb length. When two BDU-50s were released, only one was tracked. No data were obtained for BDU-33 munition releases. Video bomb scoring data were used as the truth source for comparison with impact position predictions by the SPADS radar. Average errors ranged from 60-100 feet. In all cases, the track identification process for data post-processing required extensive human operator effort to determine which tracks generated by the radar belonged to which objects.

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INTRODUCTION

General

This technical information memorandum presents the test procedures, test results, and conclusions and recommendations for the characterization of the Spaceport Arrival and Departure System (SPADS) radar in terms of functionality and performance for potential use as a single-station time-space-position information (TSPI) source. Testing was conducted at Edwards AFB, California from 6 April to 4 May 2005. Seven test flights were flown in an F-16B for a total of 7.2 flight hours. Each test flight included a T-38 chase. Test events included eight single-ship orbits, six formation events, 27 BDU-50 drops and 12 BDU-33 drops.

Testing was requested by the Range Division of the Air Force Flight Test Center (AFFTC/ENR), Edwards AFB, California. The assigned Air Force Priority Rating was six. The responsible test organization was the 412th Test Wing, Air Force Flight Test Center, Edwards AFB, CA. The AFFTC job order number was M05C6000. The test was executed by the assigned test team members from USAF Test Pilot School Class 04B.

Background

The SPADS was a mobile multi-frequency continuous-wave (MFCW) radar, built by Weibel and mounted onto a Kineto Tracking Mount (KTM). The radar system was obtained by AFFTC/ENR for use as a single-station TSPI source for missions conducted within the R-2508 complex. This test program characterized the functionality and performance of the radar.

The truth sources used for comparison were the advanced range data system (ARDS) pod, cinetheodolites (Cine-Ts) and the video bomb scoring (VBS) system. The SPADS radar was under consideration as an eventual replacement for these systems, and a comparison was useful in determining if the SPADS had improved capabilities. ARDS pods, while very accurate, were expensive and not available for all aircraft. Cinetheodolites, while accurate, were very expensive and video processing time could take weeks. Small munitions (BDU-33s) could not be tracked at all by the cinetheodolites, and the system was unreliable. The VBS was accurate, cheap and readily available, but dependent upon manual operation to determine impact positions. During the test, the SPADS radar system was also manually controlled, though an upgrade to an automatic tracking mode was planned.

Flights

For each test mission, the F-16B test aircraft was loaded with one of the following configurations. Table 1 summarizes the test flights.

Configuration A:

- ARDS Pod (Station 9)
- Six BDU-50s (three each, Stations 3 and 7, loaded on TER-9As)
- 300 gallon centerline tank (Station 5)

Configuration B:

- ARDS Pod (Station 9)
- Twelve BDU-33s (six each, Stations 3 and 7, loaded in SUU-20s)
- 300 gallon centerline tank (Station 5)

Table 1, Summary of Test Flights

DATE	Tail Number	Flight Time (hours)	Configuration
06 Apr	80-0635	1.0	A
11 Apr	80-0635	1.0	A
15 Apr	80-0635	1.0	A
26 Apr	92-0454	1.1	A
27 Apr	92-0454	1.1	A
29 Apr	92-0454	1.0	B
04 May	92-0454	1.0	A

Test Item Description

Radar

Hardware

The system under test was the SPADS radar, which was a MFTR-2100 multi-frequency trajectory radar system based on an X-band continuous wave (CW) Doppler radar antenna. In this document, the terms “SPADS” and “Weibel radar system” are synonymous. The radar system was mounted on the TC-2100 Tracking Controller with the transmitter and receiver antennas placed as shown in figure 1.

The MFTR-2100 system consisted of the following components:

- MFDR-2100 Multi-Frequency Doppler Radar Antenna
- OM-2100 Oscillator Module
- Power Supply
- TC-2100 Tracking Controller
- RTP-2100 Real Time Processor
- RTDS-2100 Real Time Data Storage
- IC-2100 Instrumentation Controller
- T-2100 200/400 VAC Transformer
- Boresight Optics With Video Monitor
- Kineto Tracking Mount - Model Number TR 26819B
- Control Logic Unit (SCLU) Alpha - Model Number 100-01

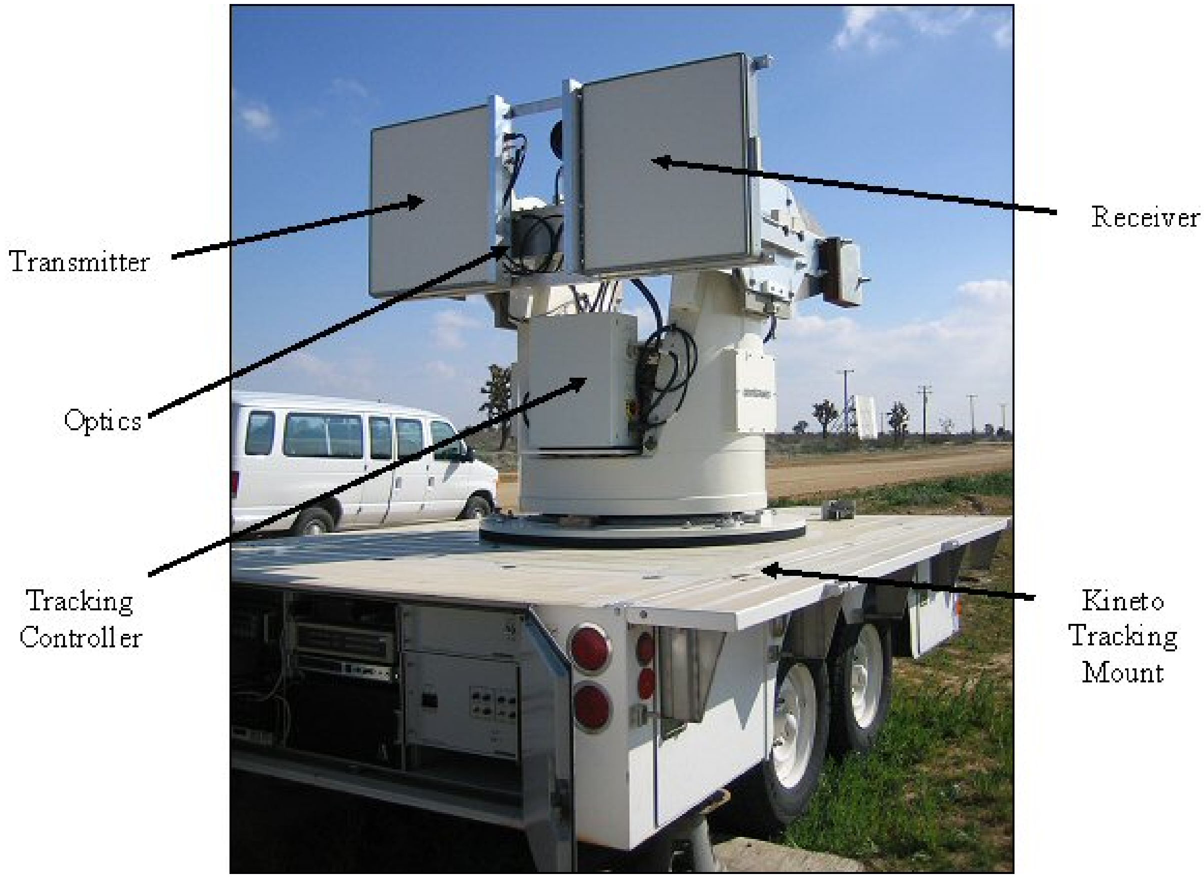

Figure 1, Weibel MFTR-2100 Radar

The SPADS radar operated in the X-band with adjustable frequencies from 10.40 to 10.55 gigahertz. The OM-2100 oscillator module generated two transmitting frequencies, F1 (CW for angle tracking and Doppler measurements), and F2 (jittering CW or multi-frequency CW for range measurements). The MFDR-2100 antenna was comprised of 128 micro-strip antennas with horizontal polarization. The antenna included the transmitter module and the receiver module. The transmitter simultaneously transmitted both frequencies by high-power solid-state amplifiers (HPA) with automatic control for constant output power. From the reflected signals, the receiver generated eight channels, four for F1 and four for F2. The antenna had a maximum gain of 37 decibels and operated with variable beam widths from 2.5 by 2.5 degrees to 10 by 10 degrees with an average CW output power of 160 watts.

Software

The WinTrack© software package was the main operator interface during setup, mission execution, and post-processing. The software ran on a Pentium PC and had the following capabilities:

- Mission Planning
- Antenna Control, Set-up and Diagnostic
- User Selectable Real-Time Display of Multiple Tracks
- Play Back

- Post-Processing Capabilities to Include:
    - Multi-object tracking (MOT)
    - Coordinate transformation
    - Curve fitting
    - Trajectory modeling

This software package automatically generated separate tracks for objects during post-processing of the radar output. A track was defined as a continuous measurement of range, velocity, azimuth angle and elevation angle for a single object. These tracks were assigned sequential numerical references and the time and parameters were recorded for each of the tracks. The desired parameter limits could be changed within the software and were calculated from the raw Doppler radar data relative to the SPADS radar position. During a measurement, if an object was lost and reacquired, multiple tracks were generated for the object. All tracks could be saved digitally for further analysis, and these tracks were used in the analysis described in this test plan. More information about software configurations can be found in the WinTrack© User's Guide (reference 1).

Operating Modes

The Weibel radar system had six modes of operation:

- Active Real-Time Tracking
- Preprogrammed Illumination
- Fixed-Head Illumination
- Manual Tracking
- Slaved Mode Operation
- Scanning Mode

For these tests, the only available tracking method was manual tracking by an operator using KTM optics. More complete information about the system operating modes can be found in the Weibel radar user's manual (reference 2).

Aircraft

F-16B

The Block 15 F-16B was a two-seat, single-engine supersonic aircraft built by Lockheed Martin. It was powered by a single Pratt & Whitney F100-PW-220 engine, had an analog flight control system, retractable gear, and automatic scheduling flaps and slats. During the test, two versions of the aircraft were flown. The first version was the "American jet", which was a standard Block 15 aircraft with Z2 software. The second version was the "Coral Phoenix jet", which was a foreign military sales version of the aircraft with a different software load and some minor hardware differences. See reference 3 for more information concerning the F-16B. Differences in test planning and execution for the two aircraft types are outlined in appendices A and B.

T-38

The T-38 was a two-seat dual-engine supersonic advanced trainer built by Northrop. It had a hydraulic irreversible flight control system and was powered by two J-85-GE-5 engines. During the test it was used as a safety chase as well as a target aircraft for the formation test points.

Munitions

BDU-50

The BDU-50 was an inert 500 pound practice version of the Mk-82. There were no explosives or fusing within the BDU-50 and the weight and ballistics characteristics were the same as the Mk-82. Three BDU-50s could be carried at a single station on a triple ejector rack (TER). The munition was a ballistic free-fall, unguided weapon approximately 6 feet in length.

BDU-33

The BDU-33 was a 25 pound practice munition that modeled the ballistics of the Mk-82. Six BDU-33s could be carried at a single station with a SUU-20 suspension unit (SUU). The BDU-33 was approximately 12 inches in length, and contained a small explosive charge for impact point marking.

Range Instrumentation

ARDS Pod

One ARDS pod was carried by the test aircraft for each test mission. Station 9 was exclusively used during the test for consistency. The ARDS Pod used differential GPS data to record aircraft position throughout the test. Positional data were obtained from the TSPI office of the 412TW/ENRE Range Division relative to the SPADS radar site. The documented ARDS pod position accuracy was within 10 feet and velocity data within 1 foot per second.

Cinetheodolites

The cinetheodolite was a high speed camera used to track a munition from release to ground impact. Pointing angles from several cameras were used to triangulate position information. The system's documented position accuracy was within 2.0 feet. Five cinetheodolites were requested for the missions in which BDU-50 tracking occurred. Two cinetheodolites were the minimum number required for position information.

VBS

The Video Bomb Scoring (VBS) system was comprised of two video cameras pointing at the target area. Similar to the cinetheodolites, the cameras used triangulation to determine impact position. This position was referenced to the center of the target in order to provide scoring to aircrews. The documented accuracy of the system was within 3.0 feet.

Test Objectives

The overall test objective was to characterize the SPADS radar system in terms of functionality and performance for potential use as a single-station time-space-position information (TSPI) source within the R-2508 complex. The tests included object tracking compared to various truth sources. Aircraft tracking was compared to ARDS pod data, munition trajectory tracking was compared to cinetheodolite data, and bomb scoring capability was compared to VBS data. Multiple-object tracking capability was also demonstrated. Specific objectives were:

Object Tracking

Demonstrate the ability of the SPADS radar system to acquire and track aircraft to include formation events with a chase aircraft within R-2508, and single and multiple munitions within the West Range.

Test Aircraft Tracking

Compare the TSPI data generated by the SPADS radar system to ARDS pod TSPI for test aircraft within R-2508.

Bomb Trajectory Tracking

Compare the SPADS radar munition trajectory data with cinetheodolite TSPI data of BDU-50 deliveries.

Bomb Impact Scoring

Determine the error in impact position predicted by the SPADS radar system while used as a bomb scoring tool compared to the VBS.

All test objectives were met.

Limitations

No limitations were experienced.

TEST AND EVALUATION

Test Procedures

Airspace Operations

Buckhorn MOA, West Range, Alpha Corridor

The test was conducted using the Buckhorn Military Operating Area (MOA), the West Range, and the Alpha Corridor. Two targets within the West Range were used for munitions deliveries, Precision-Bombing targets 1 and 10 (PB-1 and PB-10). For more information concerning the airspace and procedures, see reference 4.

The test pilot activated the airspace prior to takeoff. After takeoff, a turn was executed direct to the range airspace. The test pilot requested and received flight lead control for all missions, and set up for the first event, a range clearing and altitude calibration pass. Figure 2 illustrates the significant points on the range, including the contact point (CP), initial point (IP), the targets, and the SPADS radar. The hashed regions show the no-attack sectors required by the safety package (no attacks allowed within 10 degrees of the SPADS radar). The orbit between the CP and the IP was used for the single-ship and formation maneuvering events.

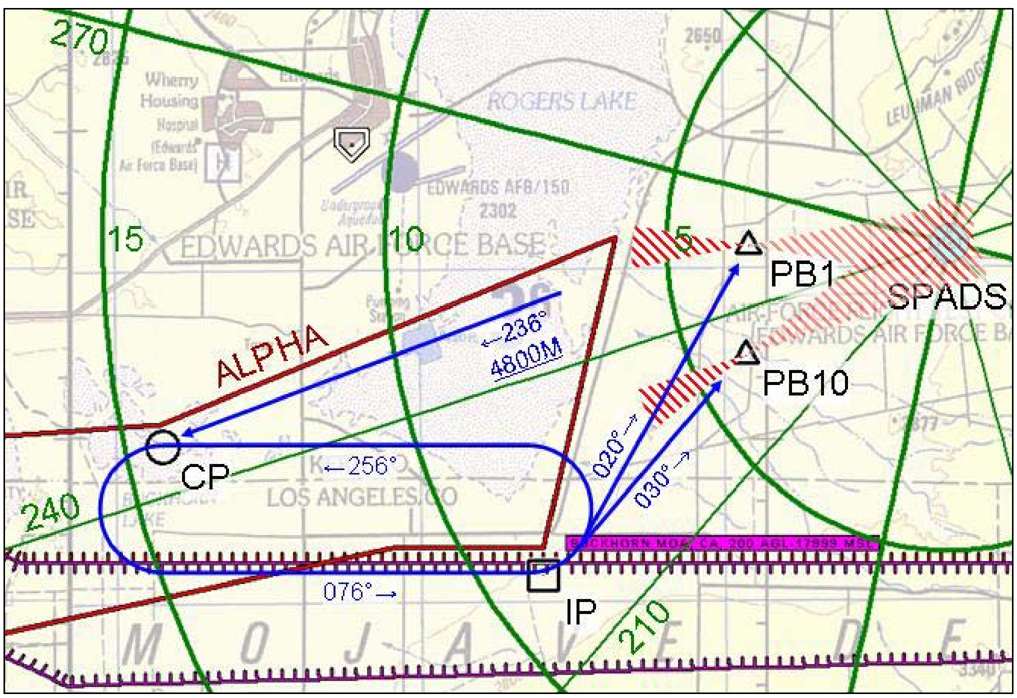

Figure 2, Test Airspace and Flow

Target attacks were flown from the IP to one of the two targets. Flying this ground track ensured the correct attack heading and appropriate avoidance of the no-attack sectors. After the weapon was released, the aircraft would enter a holding pattern while the SPADS operator tracked the weapon to impact.

Scheduling and Coordination with SPORT

A controller monitored all test missions on the dedicated mission frequency. The controller was briefed by phone before the mission on the planned airspace usage and event sequence. Although the test aircraft had flight lead control, standard range communications were made to ensure high situational awareness on the part of all participants.

Flight Operations

Attack Planning

Sixteen attacks were planned and executed for munitions delivery events. Four release parameters (altitude, airspeed, flight path angle, and aspect angle) were varied between high and low values for each attack. These variations led to four basic attack types, executed at high and low speeds on two targets. The attack types were 500-foot levels, 5000-foot levels, lofts, and 30-degree dives. An example card with all attack parameters is shown in Appendix B, along with detailed planning information for each attack.

Designation Gameplan

The primary designation gameplan for all attacks was a direct designation using the F-16 radar in Doppler-beam sharpening (DBS) mode. This designation was made inbound to the initial point (IP). As shown in Figure 2, a common IP was used for all attacks to ensure repeatability and correct alignment. The IP was visually significant, and provided the crew a head-up display (HUD) system update capability prior to turning toward the target. A last-chance update was made after turning toward the target using the HUD symbology. Another update point was chosen for the outbound leg, allowing the test crew the opportunity to fix system errors while holding between passes. Detailed descriptions of these procedures are included in Appendix A.

Acquisition Orbits

SPADS radar acquisition of the test aircraft was critical to the test, and was required before each weapon delivery or flight event. The acquisition took considerable time, and orbits were developed to minimize delay. Orbit planning considerations and location specifics are contained in Appendix A.

The time required to perform these orbits in order to use the SPADS system as a TSPI source was unreasonable for typical range customers. The procedures could be greatly simplified for the test assets if the SPADS system incorporated a cueing system. Cinetheodolites, which use the same mounts and similar operating interfaces, utilize a Test Evaluation Command and Control System (TECCS) cuing interface to provide initial acquisition capability. **Add TECCS cueing capability to the SPADS system to decrease or eliminate acquisition delays (R1)[1].**

[1] Numerals preceded by an R within parentheses at the end of a paragraph correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report

Radar Operations

The test aircraft was visually tracked from the SPADS radar site via the camera attached to the KTM and linked to the video inside the control van. The video operator was able to follow the aircraft during the entire pattern by manually moving the KTM. Aircraft acquisition over the target almost always required assistance from another person standing outside the van, visually spotting the aircraft and helping the video controller in steering the KTM to the aircraft position. After the test aircraft was acquired, manually tracking it was easy when the target was within five miles from the radar. When the distance increased beyond this range, especially if the aircraft was directly outbound or inbound, tracking became much more difficult.

Solar angles were calculated using Solar and Lunar Almanac Predictions (SLAP) version 1.3. Flights were scheduled only when the sun was not within 30 degrees of the aircraft when viewed from the SPADS radar. This was to ensure the sun was not in the radar operator's field-of-view during tracking, which could cause wash-out and increase tracking difficulties.

Test Results

Object Tracking

An example of the Doppler radar output from a loft delivery at 1,000 feet AGL on PB-1 (Test Point 2.27) is shown in Figure 3. This graph shows the raw radar return strength in decibels (dB) divided by the frequency at specific closure velocities (negative velocity corresponds to decreasing range) as a function of time. Stronger signals, shown in white, correspond to the objects being tracked in the field of view of the radar. The time axis at the bottom is the elapsed time from the beginning of data recording. Initially, there are two objects in the tracking field-of-view (FOV), the test aircraft and chase aircraft. At a time of approximately 126.5 seconds, a third object appears when the bomb is released from the aircraft. As the bomb is kept in the center of the FOV while it descends, the test and chase aircraft exit the FOV. The bomb is tracked to the ground, where ground clutter causes returns at lower velocities (top right of the graph).

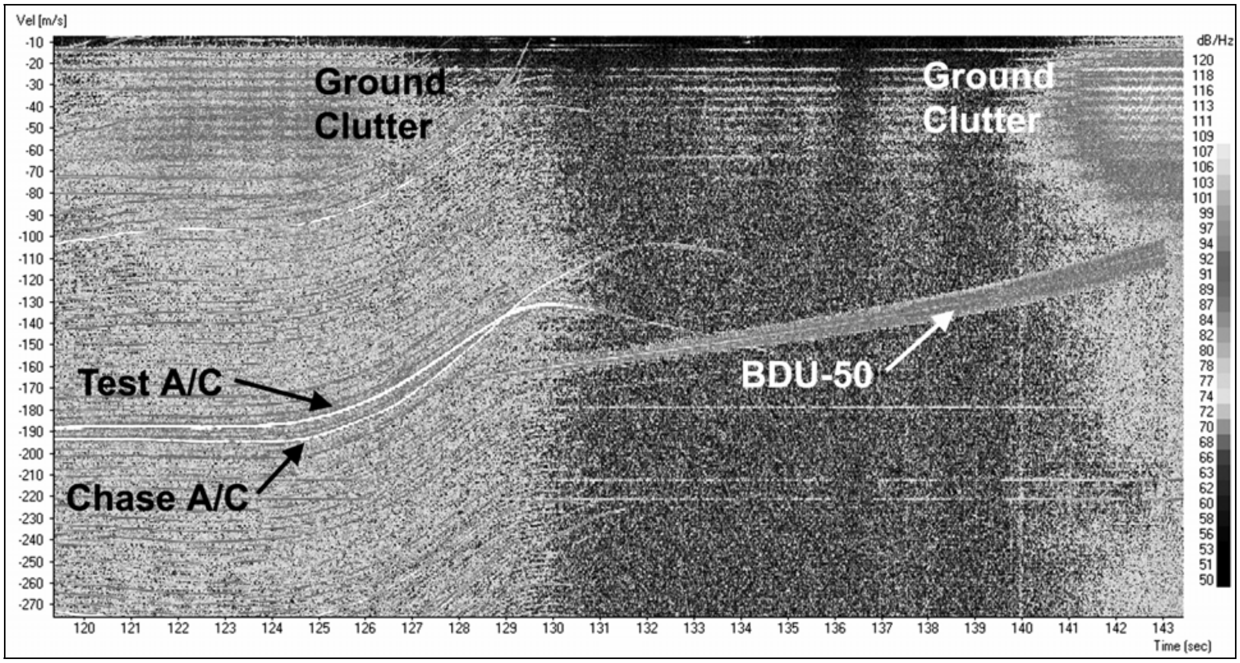

Figure 3, Doppler Radar Returns During a Loft Delivery (Test Point 2.27)

A filtering system using Fast Fourier Transforms within the WinTrack© software was used to determine which returns represented actual objects and then to create track data for each. The results of this post-processing yielded elevation angle, azimuth angle, and velocity as a function of time for each track, as shown in figures 4 through 6. In the software, each of the tracks was represented by a different color with a grayscale background representing the strength of the background noise. In these figures, the tracks were converted to a grayscale format and the background eliminated for clarity. The elevation and azimuth angle data are referenced by the phase shift of the return signals from the object. A zero degree phase means that the object is at the center of the field of view of the radar and is the object being followed optically by the system operator.

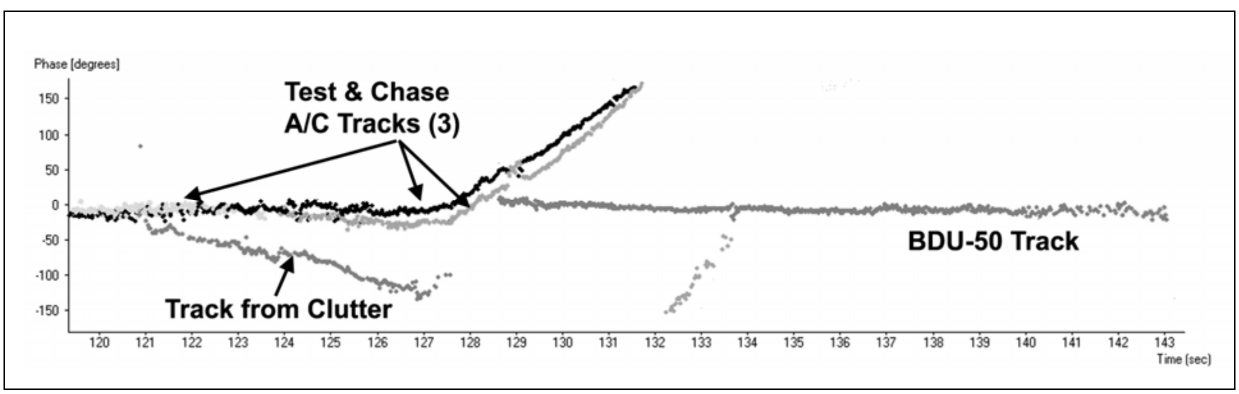

Figure 4, Elevation Angle Track Data for a Loft Delivery (Test Point 2.27)

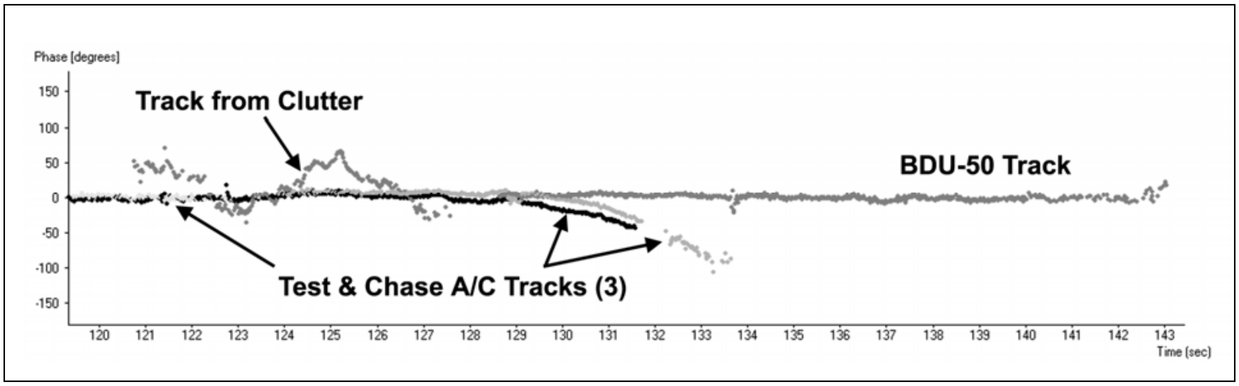

Figure 5, Azimuth Angle Track Data for a Loft Delivery (Test Point 2.27)

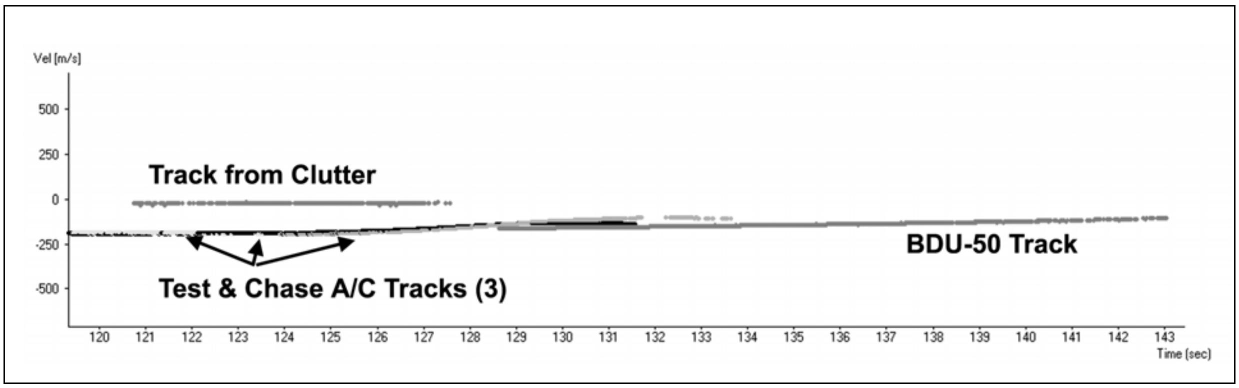

Figure 6, Closure Velocity Track Data for a Loft Delivery (Test Point 2.27)

For this maneuver, there were three main errors in track generation. First, an extra track was created from the ground clutter returns during flight at 500 feet above ground level (AGL) before the loft delivery. While the elevation and azimuth angles of the ground clutter were similar to the aircraft (the absolute elevation angle was approximately zero degrees before delivery), the velocity of the measurement for this track was a constant 15 meters per second and clearly distinguishes this track from the test and chase aircraft tracks. Second, three tracks were generated for the two aircraft in the FOV. The return from the background clutter caused the gain threshold to increase, and one aircraft track was lost. When the clutter level reduced to allow tracking of the aircraft again, it was considered a new object by the software. Lastly, the tracks for the two aircraft merged shortly after the BDU-50 was detected, at a time of 129 seconds. The aircraft track designated by the light gray merges into the aircraft track designated by black and then separates again 0.5 seconds later. All three of these errors led to changes in the total number of tracks recorded for the three objects (test aircraft, chase aircraft & BDU-50) during the event.

For each of the bomb drops, the number of tracks was recorded and divided by the number of objects in the event. These data are shown in Table D-4. As an example, test point 2.27 recorded five tracks, as already discussed, for only 3 objects which yielded a ratio of 1.67. The intent of this investigation was to determine how many tracks the radar would allocate during the flight of the test and chase aircraft and the bomb after release. The data in Table D-4 show that

while the radar usually tracked the appropriate objects, sometimes it missed one object or created multiple tracks for a single object.

These errors were a result of several factors. The radar did not always create a track for the chase aircraft. In some instances, the chase aircraft was “masked” or hidden behind the test aircraft. Additionally, the bomb was not always tracked during the low altitude deliveries due to background clutter. Of note, test points 2.35, 2.36 and 2.41 were level and dive releases of two BDU-50s at a 50 millisecond spacing. The SPADS radar was not able to determine the presence of two bombs in any of these cases. Test points 2.1-2.16 (with BDU-33 drops) are not discussed since the SPADS radar was not able to track the BDU-33 munitions at any time.

The percentage of the bomb fall time tracked by the SPADS radar was also recorded. The complete bomb fall time was calculated from the release time provided by the cinetheodolites and the impact times recorded by VBS. For test points 2.17 and 2.19, both of which were level deliveries at 500 feet AGL and 400 knots calibrated airspeed (KCAS), the SPADS radar could not generate any tracks due to background clutter. The rest of the tracking time percentages range from 58.3-100% as shown in Table D-4, in Appendix D.

The most significant lesson from this data processing procedure was the extent to which human operator input was required to generate the proper tracks for data reduction. The errors previously discussed each caused increased workload during analysis. Extra tracks had to be deleted or reassigned. This occurred often during munition release when the close proximity of objects caused enough scatter for the software to err when assigning data to separate tracks. It was a time consuming process to combine multiple tracks for the same object, especially when the raw data had lower signal-to-noise ratios. It was not always clear to which object the track data belonged.

The formation events listed in Appendix C were completed within the FOV of the radar, and track files were generated. The same racetrack patterns used for single aircraft tracking were again utilized, and multiple formation events were completed during each lap of the pattern. The WinTrack© software generated between 16 and 25 tracks for each lap. As with the munition drops, the radar generated extra tracks due to background clutter. Also, tracks were missing for the chase aircraft for much of the pattern and new tracks were generated each time the aircraft made a 180 degree turn and the radial velocity went through zero. Overall, similar problems with track generation led to increased effort by the human operator to assign the tracks to the proper objects.

All the errors described here required human operator correction during post-processing. This increased the time required to process the data and return a useful product to the customer. **Modify the filtering system used by the WinTrack© software so that proper tracks can be generated with less human operator intervention (R2).**

Test Aircraft Tracking

Detailed results of the error statistics from the single-ship tracking at each test point are shown in Table D-1 in Appendix D. The truth source data used were obtained from the ARDS pod

referenced to the GPS-surveyed location of the SPADS radar. While the ARDS pod was located on station 9 of the test aircraft, the TSPI data were referenced to the aircraft's nose.

Slant Range Errors

The slant range errors shown in Appendix D are predominantly positive, meaning the SPADS radar returns a larger range than the ARDS pod. All data shown in Table D-1 were recorded with the aircraft flying towards the radar. During the outbound portions of the pattern, when slant range was increasing, the SPADS radar recorded a slant range shorter than the ARDS pod. At the point where the aircraft was traveling perpendicular to the line of sight from the SPADS radar, the slant range error passes through zero. The top graph in Figure 7 shows the slant range measurements of the SPADS radar and ARDS pod truth source were essentially the same. The bottom graph shows the error in the SPADS measurement. This phenomenon was believed to be caused by the SPADS radar tracking reflections from parts of the aircraft behind the nose such as engine intake, tail, and wing roots during the inbound portions of flight. While outbound, the radar continued to track the center portions of the aircraft, which were then closer to the radar than the ARDS reference point at the aircraft's nose.

The magnitudes of the error means were all within one aircraft length of 45 feet except for test point 3.1, 3.9 and 3.13. All of these points were at the low values of the range (<6 nautical miles) and elevation (<1000 feet AGL) factors. The errors for test points 3.9 and 3.13 are an order of magnitude higher and these points were at the high airspeed (>520 KCAS) factor. Examining a time history of the range errors shows a sharp increase in the error of over 1500 feet during the inbound portion of the racetrack pattern used during single aircraft tracking. The slant range was well within the unambiguous range for the transmitting frequencies used (Reference 1). It is not known what caused these large errors.

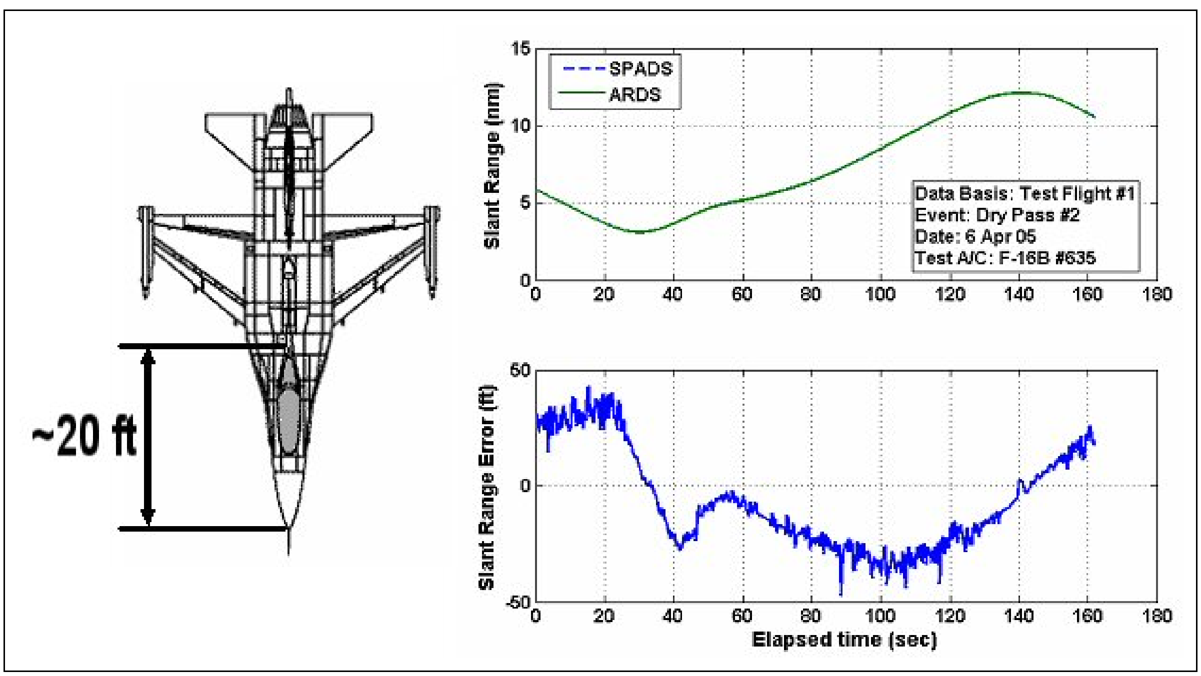

Figure 7, SPADS Radar Tracking Points

Radial Velocity Errors

The magnitude of the radial velocity errors shown in Figure 8 are all within 7 feet per second. The errors are larger for the test points flown at higher flight path angles to the radar, where the aircraft was flying close to the Doppler “notch”, in which the radial velocity of the target was too low to distinguish from ground clutter. Figure 8 shows that as the aircraft changes direction with respect to the radar, and the radial velocity changes sign, the error magnitude increases from below 1 foot per second to around 5 feet per second.

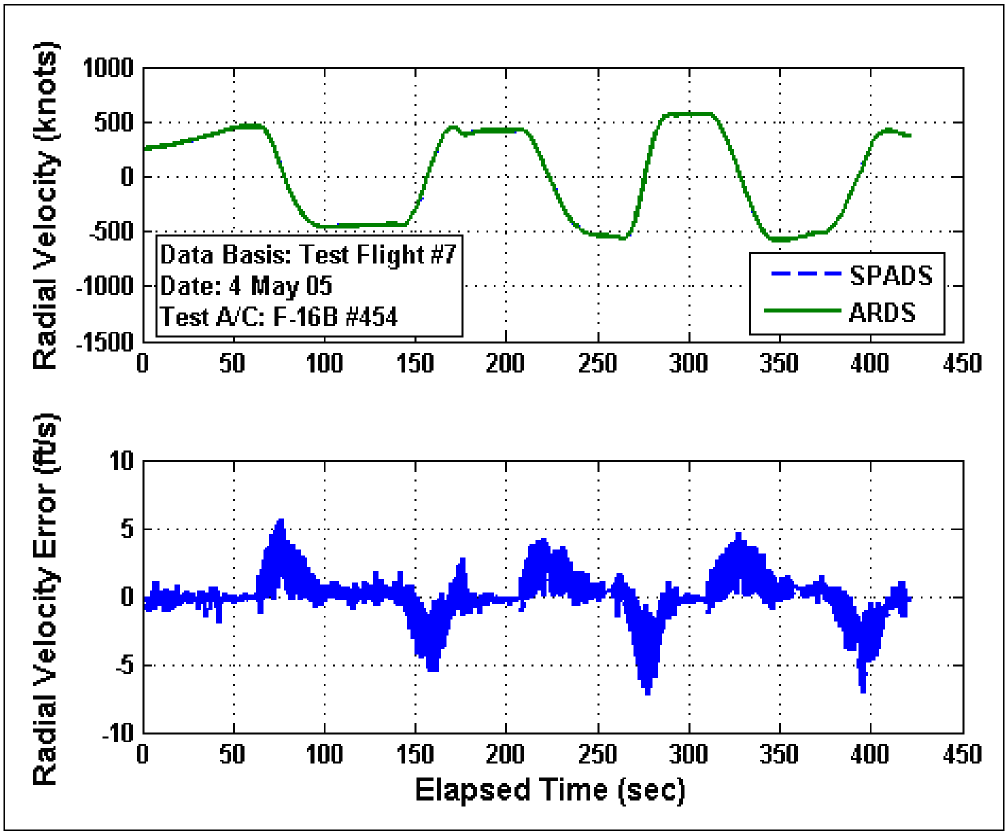

Figure 8, Radial Velocity and Errors

Elevation Angle Errors

The average and median elevation angle errors shown in Table D-1 of Appendix D were all between 0.08 and 0.27 degrees. This led to a maximum position error of 290 feet at a range of 10 nautical miles. The standard deviation of the errors was small enough to suggest that the elevation angle measurements are precise, but there was a bias in the measurement causing the accuracy to be decreased. It was noted that this bias in the elevation angle error was greater at higher elevation angles.

The elevation angle error data were plotted against the elevation angle in Figure 9. In this figure, only every 50th data point was plotted for clarity. The scatter at lower elevation angles was evident, as would be expected from the ground clutter at lower angles. The two test points (3.6 and 3.14) at which the standard deviation was larger than the error itself were both conducted at the low value of the altitude factor (<1000 feet AGL) and the large value of the range factor (>10nm), where the signal-to-noise ratio was the lowest. At higher angles, the scatter decreased, but the error grew larger at a ratio of 0.02 degree/degree. **Investigate the source of the angle-dependent elevation angle error (R3).**

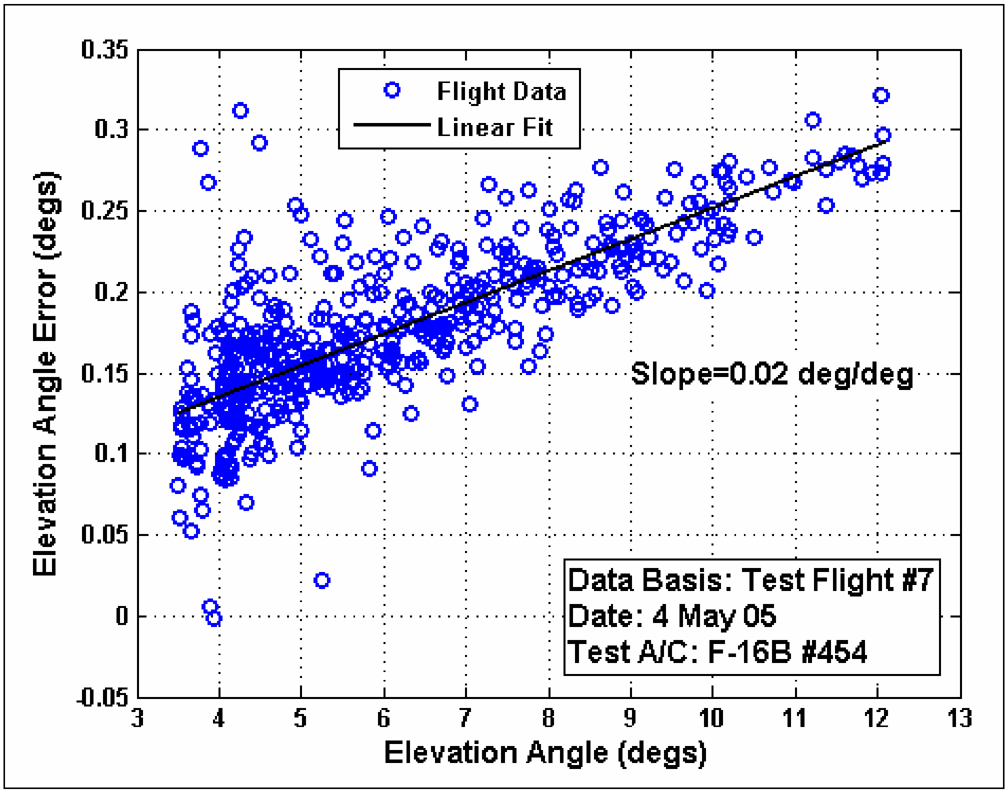

Figure 9, Elevation Angle Error as a Function of Elevation Angle

Azimuth Angle Errors

The azimuth angle error statistics are presented in Table D-1 in Appendix D. The errors were determined by subtracting the truth source calculated angle from the SPADS measurement. The angles are measured clockwise, with 0 degrees corresponding to true north. The azimuth angle errors from the SPADS radar measurement were all less than 0.18 degrees in magnitude, translating to a position error of 190 feet at a range of 10 nautical miles. The errors in azimuth angle, shown in Figure 10, were positive when the azimuth angle was decreasing and negative when the angle was increasing. The errors were also higher when the rate of change of azimuth angle was higher.

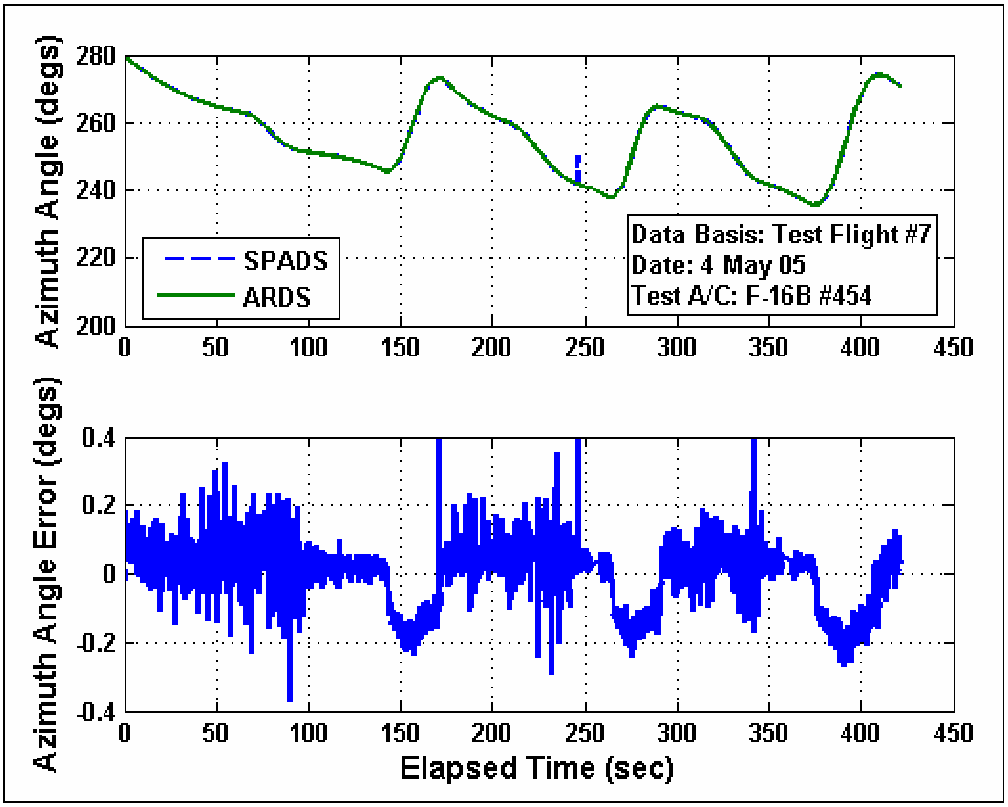

Figure 10, Azimuth Angle and Errors During Single Aircraft Tracking

In the plot of the azimuth angle throughout the flight, there are three distinct phases when the azimuth angle was decreasing and three phases where the angle was increasing. The average rate of change of azimuth angle was found for each of these six phases. Over the same time periods, the median azimuth angle error was found. These six points are plotted in Figure 11. A linear fit using these six points yielded a line with a slope of -0.11 degrees/(degree/second) and an intercept very close to 0 degrees. The azimuth angle error was shown to be dependent upon the rate of change of the azimuth angle. **Investigate the source of the rate-dependent azimuth angle error (R4).**

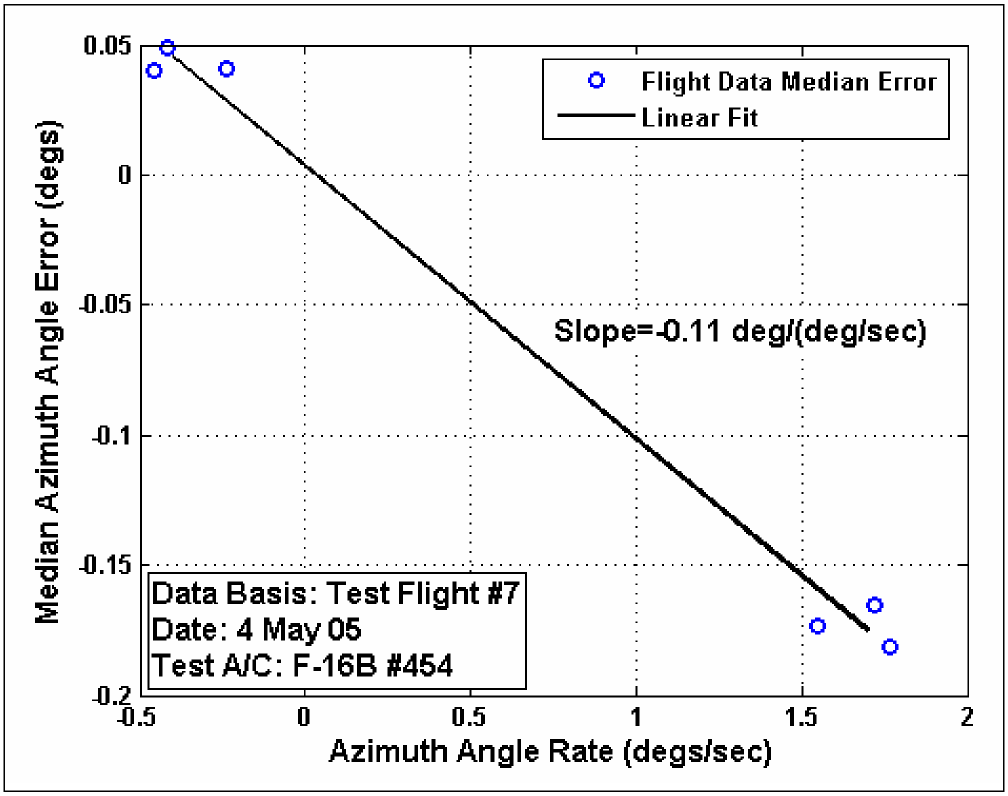

Figure 11, Median Azimuth Angle Error as a Function of Angular Rate

Design of Experiments Analysis Results

Design of Experiments (DOE) statistical analysis was used as a way to mathematically formalize the interactions described in previous sections as well as to determine other interactions not readily observed in the data. The intent of the DOE analysis was to reveal any dependence of the SPADS TSPI errors upon four factors: range from the SPADS radar, AGL altitude, flight path angle, and calibrated airspeed. A more complete description of the process undertaken as well as plots of the analysis results are presented in Appendix F.

The slant range errors were shown to be affected by the range, AGL altitude and airspeed factors. At low altitudes, high speeds and close range, the range error was very large. This was due to the error of test points 3.1, 3.9 and 3.13 being one to two orders of magnitude higher than the other test points. It is not known what caused these errors. The radial velocity was shown to

have higher errors when the flight path angle to the SPADS radar was high, or when the aircraft was flying near the notch. The velocity errors were lowest at the 9-10 nautical mile slant ranges. The elevation angle error was shown to depend upon the slant range and elevation. At short ranges and high elevations the error was largest. This corresponds to the increasing elevation angle error with increasing elevation angle shown in Figure 9.

For the azimuth angle, the DOE analysis showed that the errors were large when the range was short, the flight path angle to the radar was large and the speed was high. These conditions correspond to occasions when the rates of change of the angles and airspeeds were high, which agreed with the results previously shown. The smallest errors occurred at medium range (9-10 nautical miles) with the aircraft flying towards the radar at lower speeds, which were the conditions at which the lowest rates were encountered. This phenomena of larger errors during larger rates of change occurred for the other variables well.

Overall, it was much more difficult for the radar operator to manually track the aircraft and munition whenever the rates were the highest. While a direct connection between the manual tracking errors from the radar operator and measurement errors of the angles could not be definitively established here, it was probable that this connection did exist. An automatic tracking system would significantly simplify the tracking process and probably decrease system errors. **Implement an automatic tracking system based on the radar return (R5).**

Bomb Trajectory Tracking

The bomb trajectory TSPI errors for the single BDU-50 test points are listed in Table D-2 in Appendix D. The truth source cinetheodolite measurements were subtracted from the SPADS radar measurements to obtain the errors. The cinetheodolite measurements, though considered a truth source, were unreliable. In each case, four or five cameras were scheduled to achieve the TSPI office’s advertised accuracy of 3.0 feet. Multiple camera failures during each mission resulted in never having greater than three cameras tracking the bomb at any one time. In two weapon drops, no data were available due to cinetheodolite loss of contact with the bomb before the SPADS radar could distinguish the bomb from the aircraft. In two other drops, only one camera tracked the bomb. Cinetheodolite problems included the camera not triggering, running out of film, loss of contact and tracking the aircraft instead of the bomb. In about half the munition drops, only two cameras were used to generate the position data. It is not known what the accuracy was for the cinetheodolites when only two or three cameras were used to determine the position of the bomb.

Demonstration of multiple BDU-50 and single or multiple BDU-33 munition tracking was desired. For the BDU-33 test points, no data was obtained as the smaller munitions could not be tracked optically. Another technique of keeping the target in the field of view throughout the BDU-33’s time-of-fall was attempted. Again, no data was obtained with this technique. For the multiple BDU-50 releases, while the two larger munitions were clearly visible through the optics, only one munition was tracked by the SPADS radar. This was the case for the three test points, 2.35, 2.36 and 2.41, attempted during the testing.

Slant Range Errors

The median of the slant range errors were all within two bomb lengths, or about twelve feet. The one exception was test point 2.24, in which the error was over 30,000 feet. It is not known from where this gross error was derived. The averages and standard deviations of the slant range errors revealed information about the scatter of the data. For test point 2.20, the standard deviation was high though the mean error was small. This test point was a low altitude, level delivery where background clutter caused a reduced signal-to-noise ratio. Test points 2.21, 2.22 and 2.30 all had constant slant ranges for the first 1-2 seconds of the track. As this constant range approached the true range, a normal track was established. An example of this is shown in Figure 12**.** It is not known what caused this result. Removing these questionable data points brought the error and standard deviations equivalent to other test points.

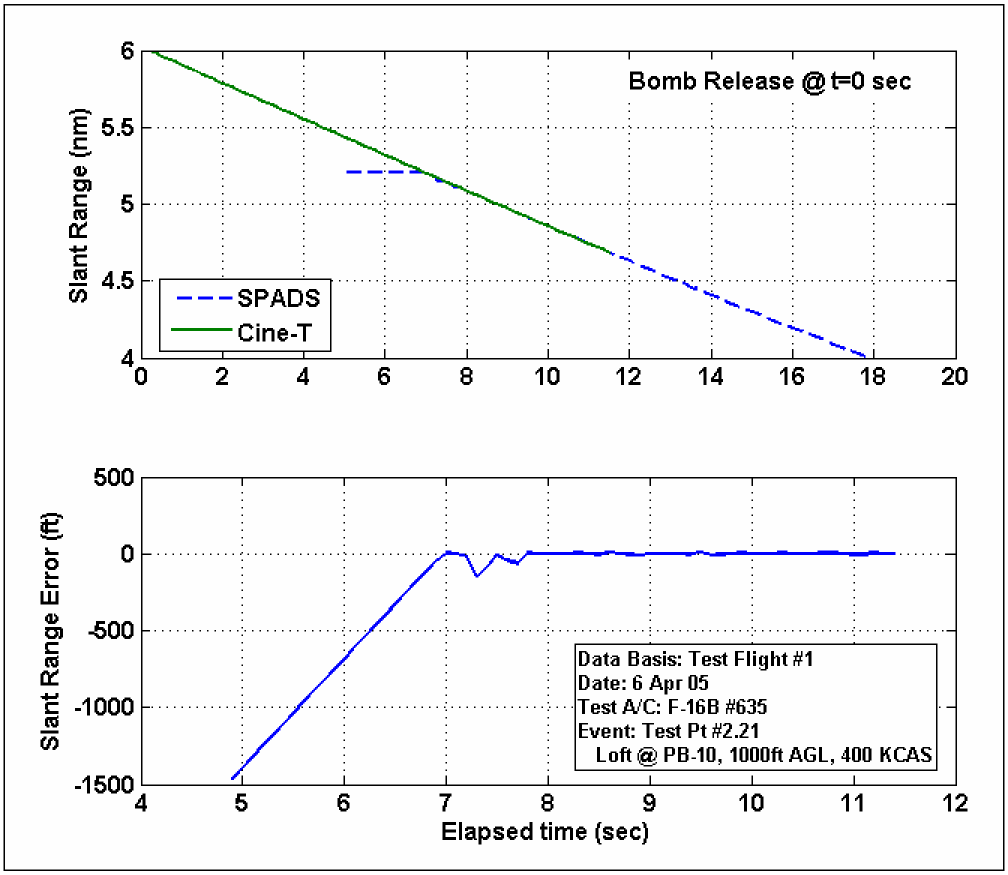

Figure 12, Example of Constant Slant Range at the Beginning of the Track

Radial Velocity Errors

The mean and median radial velocity errors are all less than 7 feet per second with standard deviations of the same order of magnitude. The two exceptions were test points 2.20 in which the low signal-to-noise ratio caused greater scatter in the measurements and 2.24 in which the radar produced highly erroneous data. The errors were also higher (4-6 feet per second magnitude) for the test points with munitions drops on PB-1 as opposed to the error for attacks

on PB-10 (0-2 feet per second magnitude). This was likely caused by the high flight path angle between the velocity vector of the bomb and the position vector from the SPADS radar, as this put the bomb’s path closer to the notch.

Elevation Angle Errors

Both the mean and median elevation angle errors showed a bias in the measurements, with the exception of test point 2.24 where the data was corrupted. The bias angle was higher, 0.42-0.55 degrees, for all the test points except points 2.31 and 2.32, where a bias of 0.28 degrees was observed. These points were flown on the fourth sortie, while the rest of the BDU-50 bomb drops were completed on sorties one and two. A change in the bias angle between these sorties was possible, either from a physical change in the KTM mount positioning or a procedural change in the WinTrack© post-processing. The source of the bias in the elevation angle must be determined and eliminated.

Azimuth Angle Errors

The median azimuth angle errors for the bomb deliveries in Table D-2 of Appendix D show a bias of 0.16-0.18 degrees. As with the elevation angles, a change in the bias was seen in test points 2.31 and 2.32, supporting the conclusion that a change in the biases occurred between sortie two and sortie four. **Eliminate the bias in the azimuth and elevation angles (R6).**

Bomb Impact Scoring

The results of the SPADS bomb impact predictions compared to the VBS impact positions are reported in Table D-3 of Appendix D. With the exception of test point 2.22, all the distance errors were within 180 feet. The most accurate predictions occurred for the loft deliveries. Two distinct groups were seen when looking at the location of the impact errors, those munitions dropped at PB-1 and those at PB-10, as shown in Figure 13. In this figure, the center position is the true impact point as measured by VBS, and true north is towards the top of the page.

The bombs dropped on PB-10 were predicted to impact at a greater range, but along the same bearing (~244 degrees true) as the actual impact positions. It is not known why the range errors were so high since the slant range errors determined from the cinetheodolites during the bomb fall were less than 10 feet. The bombs dropped on PB-1 were all predicted to be approximately 180 degrees true bearing from the actual point. In relation to the SPADS radar, this corresponded to accurate ranges but incorrect azimuth angles. More specifically, the SPADS measured azimuth angles lagged behind the true angles in the same behavior as seen for single aircraft tracking.

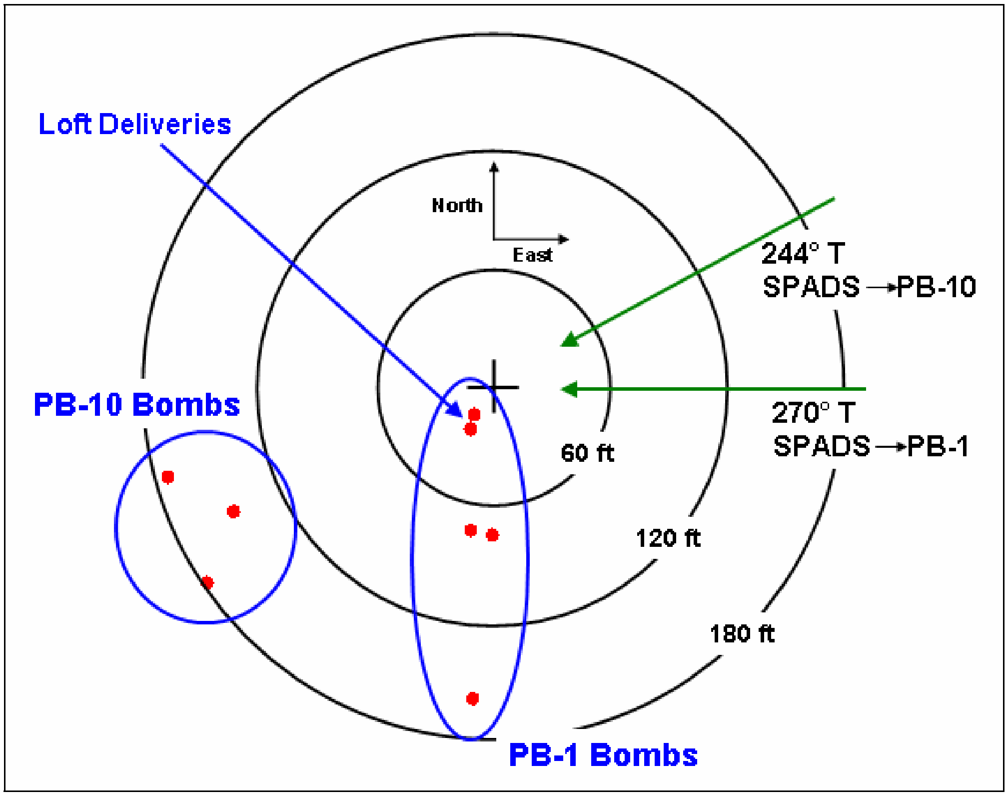

Figure 13, Polar Representation of SPADS Radar Impact Prediction Errors

Results Summary

Overall, the SPADS radar accurately tracked both aircraft flight path and munition trajectory within one to two object lengths. Radial velocities were accurate within 5 feet per second. Angular accuracies were generally within 0.5 degrees in elevation and 0.18 degrees in azimuth. The impact point predictions were within 180 feet when compared to VBS. Despite these fairly good accuracies, which could be improved further by eliminating biases, many difficulties in producing a useful product were encountered. Track data generated by the WinTrack© software required interaction by the human operator to ensure it was assigned to the proper objects in the FOV of the radar. The software sporadically produced erroneous data. Despite these problems, the SPADS radar had potential for use as a TSPI source, especially for bomb trajectory tracking, should all the previous recommendations be completed. **Accomplish further testing to assess the potential of the SPADS radar system as a TSPI source (R7)**.

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CONCLUSIONS AND RECOMMENDATIONS

The overall test objective was to characterize the Spaceport Arrival and Departure System (SPADS) radar functionality and performance for potential use as a single-station time-space-position information (TSPI) source. The testing conducted from 6 Apr to 4 May 05 met all the objectives. The TSPI data from the SPADS radar was generally within 1-2 ship lengths during single object tracking with velocity errors less than 5 feet per second. BDU-50 munition trajectory tracking led to slant range data within a bomb length and closure velocities within 6 feet per second. Lower signal-to-noise ratios encountered during low altitude operations led to higher errors and greater scatter in the data.

Acquisition of the test aircraft prior to each test event was critical to the test. This acquisition process took time and required the test aircraft to perform orbits and callout positions to the SPADS operator. The procedures could be greatly simplified for test assets if the SPADS system incorporated a cueing system.

> **Add TECCS cueing capability to the SPADS system to decrease or eliminate acquisition delays (R1, page 8).**

The tracks generated by the WinTrack© software had errors in both missing objects as well as creating objects from background clutter. Tracks also switched between objects, most notably at weapon release. While easily recognizable, the errors in track generation had to be corrected by the human operator during post-processing and extra time and effort were required to generate products for the customer.

> **Modify the filtering system used by the WinTrack© software so that proper tracks can be generated with less human operator intervention (R2, page 12).**

It was noted that this bias in the elevation angle error was greater at higher elevation angles. The scatter at lower elevation angles was evident, as would be expected from the ground clutter at lower angles. At higher angles, the scatter decreased, but the error grew larger at a ratio of 0.02 degree/degree.

> **Investigate the source of the angle-dependent elevation angle error (R3, page 15).**

The errors in azimuth angle were positive when the azimuth angle was decreasing and negative when the azimuth angle was increasing. The errors were also higher when the rate of change of azimuth angle was higher. The azimuth angle error was shown to be dependent upon the rate of change of the azimuth angle.

> **Investigate the source of the rate-dependent azimuth angle error (R4, page 17).**

The smallest errors occurred at medium range with the aircraft flying towards the radar at lower speeds, leading to a condition of the lowest rates of change for all variables. These were also the

conditions at which it was easiest for the human operator to track the aircraft manually through the optics.

Implement an automatic tracking system based on the radar return (R5, page 18).

Biases in both the elevation and azimuth angles were observed during munition tracking. A change in the bias of the elevation angle between sorties two and four was observed, either from a physical change in the KTM mount itself or in the WinTrack© post-processing of the data.

Eliminate the bias in the azimuth and elevation angles (R6, page 20).

The SPADS radar was found to generate accurate track data when operating properly. Unfortunately, proper operation was intermittent during the testing period. Currently, extensive effort must be made to track objects manually and then generate the tracks to be analyzed for TSPI data. With the completion of the recommendations made above, further testing should be performed to ensure that the SPADS radar system can produce timely, accurate data to potential customers of the Range Division of the Air Force Flight Test Center.

Accomplish further testing to assess the potential of the SPADS radar system as a TSPI source (R7, page 21).

REFERENCES

1. *WinTrack©© Users Guide*, Weibel Scientific A/S, Allerød, Denmark, 2004.
2. *MFTR-2100 Multi-Frequency Trajectory Radar System*, Weibel Scientific A/S, Allerød, Denmark, 2004.
3. *Flight Manual, USAF Series Aircraft, F-16A/B, Blocks 10 and 15*, Technical Order 1F-16A-1, Change 14, General Dynamics Fort Worth Company, Fort Worth, Texas, 15 Aug 2003.
4. Air Force Flight Test Center Instruction 11-1, Flying Operations, Edwards AFB, CA, 14 Jan 2004.
5. Air Force Instruction 11-214, Air Operations Rules and Procedures, 15 Oct 2003.
6. T.O. 1F-16A-34-1-1, Avionics and Nonnuclear Weapons Delivery Flight Manual, Change 12, 15 Sep 2003.
7. Personal Correspondence, Captain Bryon McClain, 31st TES, Edwards AFB, CA

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APPENDIX A: TEST OPERATIONS

This appendix provides a detailed description of the operations conducted by the evaluation team during test missions.

Designation Gameplan

For all attacks, a common initial point (IP) was used to ensure alignment on the correct heading, and therefore release at the correct aspect angle relative to the radar. This IP was visually significant, and was included as a target offset to allow the crews to check designation quality prior to turning final. The IP was a water tank located at the southeast end of a small road extending from Mercury Boulevard. The IP relationship to the targets is illustrated in Figure 2, and the visual reference is shown inside the white triangle in Figure A-1.

Figure A-1, IP Visual Reference

The initial aircraft inertial navigation system (INS) alignment was made as accurately as possible, with interrupted alignments and auto D-Val updates in EOR prior to takeoff. Canopy coefficients were confirmed for both aircraft used. Every mission began with a combination range clearing pass and altitude calibration on the primary target for the day (PB-1 or PB-10). If necessary, this altitude calibration was combined with a radar fix to ensure a tight system. See the F-16 avionics manual (reference 6) for more information concerning aircraft systems.

The primary designation gameplan was always to perform a direct aimpoint designation with the F-16 radar prior to the IP. This was done in Doppler-beam sharpening (DBS) mode to the maximum extent possible. If any doubt existed about the system accuracy, the IP could be used to check or fix the designation. After turning final, the designation was further refined with head-up display (HUD) slews. For the low-altitude levels, continuously-computed release point (CCRP) was the primary release mode, but continuously-computed impact point (CCIP) mode was an option if the designation was suspect. For the lofts, the designation was slewed in

azimuth after turning final. In the case of Coral Phoenix jets (with no loft steering), wind corrections were made to planned pull-up ranges. The appropriate correction was to pull 0.1 nautical miles late or early for each 15 knots of headwind or tailwind, respectively. During the dives, CCIP was the primary release mode, but the run-in was flown in CCRP in order to have ranging displayed to tenths of a mile. Since roll-in range was critical, the radar designation was made as accurately as possible, and wind corrections were applied in or out .1 nautical miles for each 20 knots headwind or tailwind, respectively.

Between passes, an update point was provided outbound to make altitude calibrations or fixes if necessary. This point was the northern T-intersection in the sewage ponds south of South Base. The northern T-intersection was chosen because it was the point with coordinates most near exact tenths of minutes, since the Coral Phoenix jet would only allow coordinate entry to this level of accuracy. The update point is shown in Figure A-2.

Figure A-2, Outbound Update Point

Acquisition Orbits

It was found that acquisition at ranges outside of 10 nautical miles was difficult, since the operator was using video optics to find the test aircraft, and atmospheric attenuation as well as aircraft size made this more difficult the farther the aircraft was from the SPADS radar. Additionally, The Kineto Tracking Mount (KTM) had a malfunction when used at elevation angles greater than 10 degrees, and experienced oscillations that made acquisition difficult or impossible. The elevation angle was a function of aircraft altitude and range to the SPADS radar. The closer or higher the test aircraft was, the higher the elevation angle became. In order to reduce the amount of altitude change required between acquisition and delivery, it was desired to have the acquisition orbits at altitudes close to the run-in altitudes, which varied from 500 feet above ground level (AGL) (about level with the SPADS radar), to 12,000 feet mean sea level (MSL) (more than 9000 feet above the SPADS). Several iterations of acquisition orbits were attempted, and the test team finally settled on the orbit shown in Figure A-3.

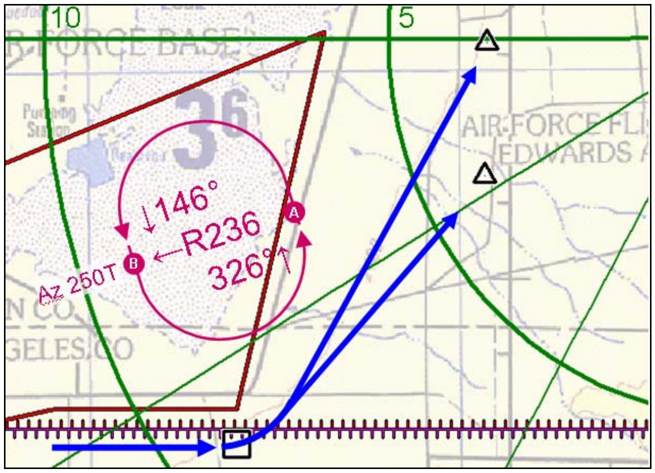


Figure A-3, Acquisition Orbit Location

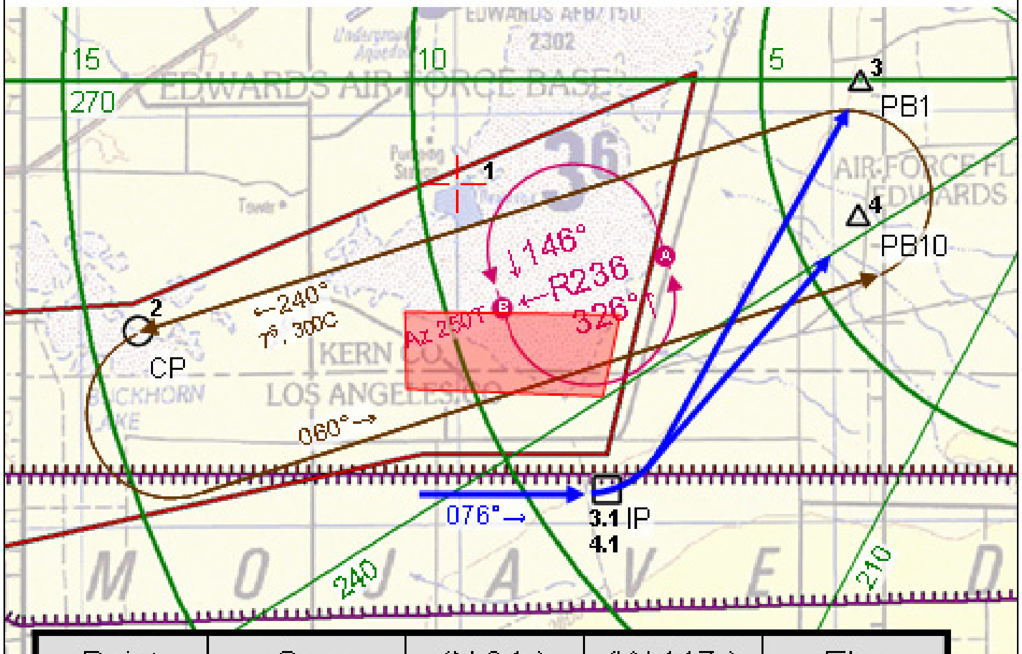
Orbit points A and B were both located at an azimuth of 250 degrees true from the SPADS radar. This measurement was made in true versus magnetic bearing since the SPADS radar interface displayed azimuth information to the operator in true. Distances and altitudes were chosen to attain a constant radar elevation angle, and two options were developed, a “high” orbit used for diving deliveries, and a “low” orbit used for all other types of deliveries. Point A was visually significant, on the edge of Rogers Dry Lake bed. Point B was reached by executing a 2-g turn at 350 knots calibrated airspeed (KCAS). The test pilot would set system steering to the SPADS radar, dial the 236 degree radial into the HSI, fly to point A, call “Approaching Hold A Low”, for example, and then rock wings when crossing the point. After one or two wing rocks, the pilot would start a climbing turn toward point B, repeat the communications and wing rock at point B, followed by a descending turn back to point A, and so on. This orbit allowed the SPADS operator to set the video camera at 250 degrees true and the appropriate elevation, and then wait for the aircraft to fly into the field-of-view and rock wings. After the radar completed acquisition and called “contact”, the test pilot would reset steering to the next target and set up for the next event. Specific parameters are shown in Table A-1.

Table A-1, Acquisition Orbit Parameters

Holding Pattern – 250°T			
Point	Rng (NM)	Alt (MSL)	Elev (°)
Low A	6.9	5,800	4
Low B	9.1	6,600	4
High A	6.9	8,800	8
High B	9.1	10,500	8

A standard coordination card was developed, which showed point locations as well as an airspace overview. An example of this card is shown in Figure A-4.

Overview / Coordination



Point	Seq	(N 34-)	(W 117-)	Elev
Ponds	1	51.909	52.504	2260
CP	2	49.885	57.980	2306
IP (brg/rng)	3.1	214.1	39348	2464
	4.1	225.2	30874	2464
PB1	3	53.158	45.387	2206
PB10	4	51.379	45.426	2376
SPADS	5	53.177	41.057	2812

Holding Pattern - Brg 250° T			
Point	Rng (NM)	Alt	Elev (°)
Low A	6.9	5^{8}	4
Low B	9.1	6^{6}	4
High A	6.9	8^{8}	8
High B	9.1	10^{5}	8

Figure A-4, Example Coordination Card

APPENDIX B: TEST PLANNING

The standard attack card is shown in Figure B-1. A detailed description of the planning process and references follows.

Levels						
Evt	MSL*/AGL	KCAS	15"	Rel	TOF	MILs
A	$7^4/5^0$	400	4.0	2.1	17.6	-
B	$7^4/5^0$	520	5.1	2.7	17.7	-
C	$2^9/0^5$	400	2.4	0.6	5.3	173
D	$2^9/0^5$	520	3.1	0.8	5.3	128

*Subtract 200 ft for PB 1

Formation	
Evt	Maneuver
I	Rte-Ftip-Rte
J	Cross
K	Turn

Lofts (3.8G MIL)					Release			
Evt	AGL	KCAS	15"	Pull	Rng	AGL	FPA	TOF
E	0^5	400	3.8	2.5	2.0	1^0	25	20.6
F	0^5	520	5.1	3.4	2.8	1^0	20	21.4

30° Dives			Roll-in			Release				
Evt	MSL	KCAS	15"	Rng	TREL	Rng	MSL	KCAS	TOF	MILs
G	11^0	300	2.5	2.4	-1	1.0	7^5	400	9.4	204
H	12^0	400	3.0	2.9	+2	1.1	7^5	520	8.2	144

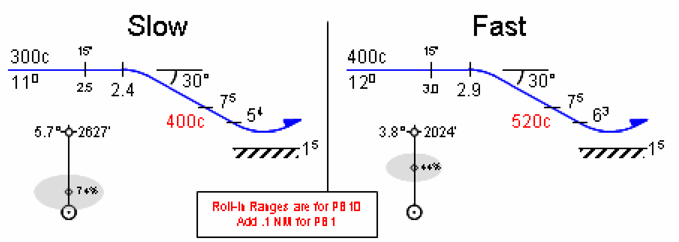


Figure B-1, Generic Attack Card

All attacks were planned in accordance with Air Force guidance (see reference 5). The first attack type was a level release at two altitudes (500 feet above ground level (AGL) and 5000 feet AGL) and two speeds (400 knots calibrated airspeed (KCAS) and 520 KCAS). Predicted release ranges, sight settings, and times-of-fall (TOF) were calculated with Combat Weapons Delivery Software (CWDS) version 9.1. Attacks were flown in continuously-computed release point (CCRP) mode following the F-16 system steering. The minimum release altitude was 500 feet AGL in accordance with the safety package.

The second attack type was a loft planned with a run-in at 500 feet AGL and both airspeed options. The planned pull-up ranges were set to achieve weapon releases at 1000 feet AGL. In order to achieve this, the release angle was 25 degrees for the 400 KCAS run-in and 20 degrees for the 520 KCAS run-in. When flying American Block-15 aircraft, the desired flight path angle was entered into the stores control panel (SCP) weapons program, and the loft steering was followed. When flying Coral Phoenix aircraft (with no loft programming option), the attacks were flown in CCRP, with pull-up executed at the planned ranges. Although the American loft

steering commands a 3.8 g pull-up, CWDS only allowed planning lofts at 4 g. All lofts were executed at 3.8 g, accepting that the releases would occur at slightly lower angles and altitudes than those calculated by CWDS. The lofts were simple to execute, but were close to several test limits; minimum altitude 500 feet AGL, minimum airspeed 400 KCAS, and maximum release load factor 4 g.

Thirty degree diving attacks were planned with releases at both airspeed options. These were direct roll-in dives, or “flip-flops”. The final portions of the attacks were planned with CWDS, and the dive entries were planned using basic trigonometry and the assumptions below. After the math was complete, an amount was added to make the run-in at an exact 1000 foot interval (i.e. 11,000 or 12,000 feet), and 0.1 nautical mile was added to roll-in range for reaction time and roll onset. Planned release altitude for both deliveries was 5000 feet AGL. The minimum release altitudes were calculated based on 5 degrees steep, with a minimum recovery altitude of 1500 feet AGL, achieved with a 4 g pull in 2 seconds. Overall, this was considered a very conservative approach, but releases at and below this altitude resulted in very short time of fall (TOF), and therefore poor data quality. All releases during the test were executed well above the minimum release altitudes.

Dive entry assumptions

- Roll-In and Roll-Out in 1 Second (180 degrees/s)
- Pull-Down at 3 g, With g-Onset in ½ Second (4 g/s)
- Constant True Airspeed From Roll-In to Roll-Out
- Temperature 80 Degrees Fahrenheit at Target Elevation with Standard Temperature Lapse Rate

Also shown on the generic attack card are references for the range at 15 seconds prior to release and sight depression settings for deliveries in which the target was visible in the HUD at release. The 15 second reference was used for the test pilot to make an advisory call to the tracking assets, and the sight depression settings were included to allow manual release capability, which was never used during the test. For the diving attacks, the time-to-release at roll-in was also calculated as an additional cue. The attacks were planned for PB-10, which was at an elevation of 2376 feet. When attacking PB-1, at an elevation of 2206 feet, adjustments were made to ensure appropriate geometry. For the level and loft attacks, the same AGL reference was maintained, resulting in a 170 foot barometric altitude difference. For the dives, roll-in range was extended 0.1 nautical miles to ensure that the aircraft would fly the correct geometry relative to the target.

CWDS outputs for each of the planned attacks are included for reference in the following pages. The term “Low” references 500 foot AGL, “High” references 5000 ft AGL, “Slow” references 400 KCAS, and “Fast” references 520 KCAS.

15sec 551T = 5.1 = 11 + POU

```
* MISSION DATA ***

:RCRAFT                                 F16AB PW220
AG INDEX                                130.0
OSS WEIGHT                              30000
INITION                                 BDU-50 LD
JSPENSION                               TER-9/A
:LIVERY                                 Loft/Toss (4.0G MIL POWER)
)FT MODE                                Angle

* TARGET DATA ***

RGET DENSITY ALTITUDE                   4251 FT
RGET ELEVATION                          2376FT    724M
RGET TEMPERATURE                        +27C      +80F
RGET ORIENTATION (Axis from North)      347M      360T
RGET DIMENSIONS:
 HEIGHT                                 25FT
 WIDTH                                  25FT
 DEPTH                                  25FT
RGET MIL SIZE AT WEAPON RELEASE         2.5 MILS
RGET MIL SIZE AT WEAPON IMPACT          2.1 MILS

** ATTACK TIMING DATA ***

IME IP TO PULL-UP                       11 SEC
IME  PULL-UP TO RELEASE                 4.30 SEC
IME IP TO RELEASE                       15 SEC
IME IP TO WEAPON IMPACT                 36 SEC

** APPROACH CONDITIONS ***

JN-IN AIRSPEED                          520C      551T      .85M      551G
JN-IN ALTITUDE (AGL=ABOVE TGT ELEV)     2876M     500A
ANGE  IP TO PULL-UP                     1.6NM     9951FT    3033M
IME IP TO PULL-UP                       11 SEC

** RELEASE CONDITIONS ***

UMBER OF WEAPONS RELEASED               1
ELEASE ALTITUDE                         3407M     1031A
ELEASE ANGLE                            20.0 DEG
ELEASE ATTITUDE                         26 DEG
IME  PULL-UP TO RELEASE                 4.30 SEC
ANGE  PULL-UP TO RELEASE                3898FT
ANGE  PULL-UP TO FIRST IMPACT           20889FT  = 3.4 NM
AXIMUM ALTITUDE OF LOFTED WEAPON        4752M     2376A

** WEAPON CONDITIONS ***

EAD/TAIL WIND CORRECTION                43.3 FT/KT
RAB CROSSWIND CORRECTION                5.4 FT/KT
ANGE  FIRST RELEASE TO IMPACT           16992FT  = 2.8 NM
IME OF FALL  FIRST RELEASE              21.36 SEC
EAPON IMPACT ANGLE                      27 DEG
EAPON IMPACT VELOCITY                   841 FT/SEC

** SAFE ESCAPE / SEPARATION NOT CONSIDERED ***

EFT WINGOVER
ANGE  WPN IMPACT TO AIRCRAFT (EGRESS)   3.0NM     18095FT   5515M
EARING  TGT TO AIRCRAFT AT WPN IMPACT   262T      249M
LTITUDE AT APEX OF LOFT WINGOVER        5250M     2874A
OFT WINGOVER RECOVERY TO A LEVEL FLIGHT EGRESS:
  FPA TO START DIVE RECOVERY            -13 DEG
  ALTITUDE TO START DIVE RECOVERY       3076M     700A
  LEVEL-OFF AIRSPEED                    468C      496T      .76M      496G
  EGRESS ALTITUDE                       2781M     405A
  EGRESS HEADING                        264T      250M
```

Figure B-2, Fast Loft Planning

** MISSION DATA ***

RCRAFT	F16AB PW220			
AG INDEX	130.0			
OSS WEIGHT	30000			
NITION	BDU-50 LD			
JSPENSION	TER-9/A			
LIVERY	Loft/Toss (4.0G MIL POWER)			
FT MODE	Angle			

426T = 3.8 = 11T PULL

** TARGET DATA ***

RGET DENSITY ALTITUDE	4251 FT			
RGET ELEVATION	2376FT	724M		
RGET TEMPERATURE	+27C	+80F		
RGET ORIENTATION (Axis from North)	347M	360T		
RGET DIMENSIONS:				
HEIGHT	25FT			
WIDTH	25FT			
DEPTH	25FT			
RGET MIL SIZE AT WEAPON RELEASE	3.5 MILS			
RGET MIL SIZE AT WEAPON IMPACT	3.0 MILS			

** ATTACK TIMING DATA ***

IME IP TO PULL-UP	22 SEC			
IME PULL-UP TO RELEASE	4.16 SEC			
IME IP TO RELEASE	26 SEC			
IME IP TO WEAPON IMPACT	47 SEC			

** APPROACH CONDITIONS ***

UN-IN AIRSPEED	400C	426T	.65M	426G
UN-IN ALTITUDE (AGL=ABOVE TGT ELEV)	2876M	500A		
ANGE IP TO PULL-UP	2.6NM	15682FT	4780M	
IME IP TO PULL-UP	22 SEC			

** RELEASE CONDITIONS ***

UMBER OF WEAPONS RELEASED	1			
ELEASE ALTITUDE	3362M	986A		
ELEASE ANGLE	25.0 DEG			
ELEASE ATTITUDE	36 DEG			
IME PULL-UP TO RELEASE	4.16 SEC			
ANGE PULL-UP TO RELEASE	2889FT			
ANGE PULL-UP TO FIRST IMPACT	15158FT	2.49 NM		
AXIMUM ALTITUDE OF LOFTED WEAPON	4598M	2222A		

** WEAPON CONDITIONS ***

EAD/TAIL WIND CORRECTION	41.7 FT/KT			
RAB CROSSWIND CORRECTION	6.1 FT/KT			
ANGE FIRST RELEASE TO IMPACT	12269FT	2.02 NM		
IME OF FALL FIRST RELEASE	20.56 SEC			
EAPON IMPACT ANGLE	33 DEG			
EAPON IMPACT VELOCITY	681 FT/SEC			

** SAFE ESCAPE / SEPARATION NOT CONSIDERED ***

EFT WINGOVER				
ANGE WPN IMPACT TO AIRCRAFT (EGRESS)	2.3NM	13699FT	4175M	
EARING TGT TO AIRCRAFT AT WPN IMPACT	251T	238M		
LTITUDE AT APEX OF LOFT WINGOVER	4967M	2591A		
FT WINGOVER RECOVERY TO A LEVEL FLIGHT EGRESS:				
FPA TO START DIVE RECOVERY	-13 DEG			
ALTITUDE TO START DIVE RECOVERY	3076M	700A		
LEVEL-OFF AIRSPEED	298C	319T	.49M	319G
EGRESS ALTITUDE	2939M	563A		
EGRESS HEADING	263T	249M		

Figure B-3, Slow Loft Planning

15" @ 551T = 3.1

```
** MISSION DATA ***

IRCRAFT                                   F16AB PW220
ROSS WEIGHT                               30000
IUNITION                                  BDU-50 LD
USPENSION                                 TER-9/A
ELIVERY                                   Level

** TARGET DATA ***

ARGET DENSITY ALTITUDE                    4251 FT
ARGET ELEVATION                           2376FT     724M
ARGET TEMPERATURE                         +27C       +80F
ARGET ORIENTATION (Axis from North)       347M       360T
ARGET DIMENSIONS:
 HEIGHT                                   25FT
 WIDTH                                    25FT
 DEPTH                                    25FT
ARGET MIL SIZE AT WEAPON RELEASE          9.0 MILS
ARGET MIL SIZE AT WEAPON IMPACT           78.7 MILS

** ATTACK TIMING DATA ***

IME IP TO RELEASE                         28 SEC
IME IP TO WEAPON IMPACT                   33 SEC

** RELEASE CONDITIONS ***

IUMBER OF WEAPONS RELEASED                1
ANGE IP TO RELEASE                        4.3NM      26059FT   7943M
IEADING IP TO RELEASE                     032M       045T
ELEASE ALTITUDE FIRST WEAPON              500A       2876M
ELEASE ALTITUDE CORRECTED FOR ALT LAG                2876M
ELEASE DIVE ANGLE                         0.0 DEG
ELEASE AIRSPEED                           520C       551T      .85M      551G

** WEAPON CONDITIONS ***

ERO SIGHT LINE AOA                        22.1 MILS
.D.F.P.                                   105.4 MILS
OTAL SIGHT SETTING                        127.5 MILS
RAB CROSSWIND CORRECTION                  0.2 FT/KT
RIFT CROSSWIND CORRECTION                 8.9 FT/KT            1.8 MILS/KT
IEAD/TAIL WIND CORRECTION                 0.2 MILS/KT
EAPON RANGE FIRST RELEASE                 0.8NM      4781FT    1457M
LANT RANGE AT RELEASE                     4807FT
OMB TRAIL                                 0.0NM      104FT     32M
IME OF FALL  FIRST RELEASE                5.25 SEC
EAPON IMPACT ANGLE                        11 DEG
EAPON IMPACT VELOCITY                     913 FT/SEC

**  SAFE ESCAPE SAFE SEPARATION DIVE RECOVERY INFORMATION ***
afe Escape not considered.
SCAPE MANEUVER                            Level Turn
 ATTACK HEADING (True/Mag)                45   / 32 DEG
 EGRESS HEADING (True/Mag)                360  / 347 DEG
 G/BANK                                   1.50 / 48
 ROLL RATE                                30 DEG/SEC
 TURN RADIUS                              4.0NM      24076FT   7338M
 TURN LEFT 45 DEGREES
EARING  TGT TO AIRCRAFT AT WPN IMPACT     340T       327M
AX FRAGMENT TRAVEL
 ALTITUDE                                 2489A      4865M
 HORIZONTAL  RANGE                        2910FT
 TOF                                      26.7 SEC
```

Figure B-4, Fast-Low Level Planning

```
** MISSION DATA ***                                        15" @ 426T = 2.4

IRCRAFT                                 F16AB PW220
ROSS WEIGHT                             30000
UNITION                                 BDU-50 LD
USPENSION                               TER-9/A
ELIVERY                                 Level

** TARGET DATA ***

ARGET DENSITY ALTITUDE                  4251 FT
ARGET ELEVATION                         2376FT     724M
ARGET TEMPERATURE                       +27C       +80F
ARGET ORIENTATION (Axis from North)     347M       360T
ARGET DIMENSIONS:
 HEIGHT                                 25FT
 WIDTH                                  25FT
 DEPTH                                  25FT
ARGET MIL SIZE AT WEAPON RELEASE        11.4 MILS
ARGET MIL SIZE AT WEAPON IMPACT         79.5 MILS

** ATTACK TIMING DATA ***

IME IP TO RELEASE                       38 SEC
IME IP TO WEAPON IMPACT                 43 SEC

** RELEASE CONDITIONS ***

JMBER OF WEAPONS RELEASED               1
ANGE IP TO RELEASE                      4.5NM      27070FT    8251M
EADING IP TO RELEASE                    032M       045T
ELEASE ALTITUDE FIRST WEAPON            500A       2876M
ELEASE ALTITUDE CORRECTED FOR ALT LAG              2876M
ELEASE DIVE ANGLE                       0.0 DEG
ELEASE AIRSPEED                         400C       426T       .65M       426G

** WEAPON CONDITIONS ***

ERO SIGHT LINE AOA                      39.4 MILS
D.F.P.                                  133.6 MILS
OTAL SIGHT SETTING                      173.0 MILS
RAB CROSSWIND CORRECTION                0.1 FT/KT
RIFT CROSSWIND CORRECTION               9.0 FT/KT             2.4 MILS/KT
EAD/TAIL WIND CORRECTION                0.3 MILS/KT
EAPON RANGE FIRST RELEASE               0.6NM      3771FT     1149M
LANT RANGE AT RELEASE                   3804FT
OMB TRAIL                               0.0NM      54FT       16M
IME OF FALL  FIRST RELEASE              5.32 SEC
EAPON IMPACT ANGLE                      14 DEG
EAPON IMPACT VELOCITY                   722 FT/SEC

*  SAFE ESCAPE SAFE SEPARATION DIVE RECOVERY INFORMATION ***
fe Escape not considered.
CAPE MANEUVER                           Level Turn
ATTACK HEADING (True/Mag)               45   / 32 DEG
EGRESS HEADING (True/Mag)               360  / 347 DEG
G/BANK                                  1.50 / 48
ROLL RATE                               30 DEG/SEC
TURN RADIUS                             2.4NM      14371FT    4380M
TURN LEFT 45 DEGREES
ARING  TGT TO AIRCRAFT AT WPN IMPACT    326T       313M
X FRAGMENT TRAVEL
ALTITUDE                                2489A      4865M
HORIZONTAL  RANGE                       2910FT
TOF                                     26.7 SEC
```

Figure B-5, Slow-Low Level Planning

```
** MISSION DATA ***

.IRCRAFT                                    F16AB PW220
ROSS WEIGHT                                 30000
UNITION                                     BDU-50 LD
USPENSION                                   TER-9/A
ELIVERY                                     Level

** TARGET DATA ***

ARGET DENSITY ALTITUDE                      4251 FT
ARGET ELEVATION                             2376FT    724M
ARGET TEMPERATURE                           +27C      +80F
ARGET ORIENTATION (Axis from North)         347M      360T
ARGET DIMENSIONS:
 HEIGHT                                     25FT
 WIDTH                                      25FT
 DEPTH                                      25FT
ARGET MIL SIZE AT WEAPON RELEASE            2.5 MILS
ARGET MIL SIZE AT WEAPON IMPACT             6.5 MILS

** ATTACK TIMING DATA ***

IME IP TO RELEASE                           15 SEC
IME IP TO WEAPON IMPACT                     33 SEC

** RELEASE CONDITIONS ***

UMBER OF WEAPONS RELEASED                   1
ANGE IP TO RELEASE                          2.4NM     14660FT   4468M
EADING IP TO RELEASE                        032M      045T
ELEASE ALTITUDE FIRST WEAPON                5000A     7376M
ELEASE ALTITUDE CORRECTED FOR ALT LAG                 7376M
ELEASE DIVE ANGLE                           0.0 DEG
ELEASE AIRSPEED                             520C      583T      .91M      583G

** WEAPON CONDITIONS ***

ERO SIGHT LINE AOA                          23.2 MILS
.D.F.P.                                     300.3 MILS
OTAL SIGHT SETTING                          323.4 MILS
RAB CROSSWIND CORRECTION                    2.0 FT/KT
RIFT CROSSWIND CORRECTION                   29.8 FT/KT          1.8 MILS/KT
EAD/TAIL WIND CORRECTION                    0.5 MILS/KT
EAPON RANGE FIRST RELEASE                   2.7NM     16180FT   4932M
LANT RANGE AT RELEASE                       16935FT
OMB TRAIL                                   0.2NM     1178FT    359M
IME OF FALL  FIRST RELEASE                  17.64 SEC
EAPON IMPACT ANGLE                          32 DEG
EAPON IMPACT VELOCITY                       1009 FT/SEC

**  SAFE ESCAPE SAFE SEPARATION DIVE RECOVERY INFORMATION ***
afe Escape not considered.
SCAPE MANEUVER                              Level Turn
 ATTACK HEADING (True/Mag)                  45   / 32 DEG
 EGRESS HEADING (True/Mag)                  360  / 347 DEG
 G/BANK                                     1.50 / 48
 ROLL RATE                                  30 DEG/SEC
 TURN RADIUS                                4.4NM     26920FT   8205M
 TURN LEFT 45 DEGREES
EARING  TGT TO AIRCRAFT AT WPN IMPACT 320T            306M
AX FRAGMENT TRAVEL
 ALTITUDE                                   2489A     4865M
 HORIZONTAL  RANGE                          2910FT
 TOF                                        26.7 SEC
```

15" @ 583T =

Figure B-6, Fast-High Level Planning

** MISSION DATA ***

IRCRAFT	F16AB PW220		
ROSS WEIGHT	30000		15"@453T = 4.0
UNITION	BDU-50 LD		
USPENSION	TER-9/A		
ELIVERY	Level		

** TARGET DATA ***

ARGET DENSITY ALTITUDE	4251 FT	
ARGET ELEVATION	2376FT	724M
ARGET TEMPERATURE	+27C	+80F
ARGET ORIENTATION (Axis from North)	347M	360T
ARGET DIMENSIONS:		
HEIGHT	25FT	
WIDTH	25FT	
DEPTH	25FT	
ARGET MIL SIZE AT WEAPON RELEASE	3.1 MILS	
ARGET MIL SIZE AT WEAPON IMPACT	6.6 MILS	

** ATTACK TIMING DATA ***

IME IP TO RELEASE	24 SEC
IME IP TO WEAPON IMPACT	41 SEC

** RELEASE CONDITIONS ***

JMBER OF WEAPONS RELEASED	1			
ANGE IP TO RELEASE	3.0NM	17992FT	5484M	
EADING IP TO RELEASE	032M	045T		
ELEASE ALTITUDE FIRST WEAPON	5000A	7376M		
ELEASE ALTITUDE CORRECTED FOR ALT LAG		7376M		
ELEASE DIVE ANGLE	0.0 DEG			
ELEASE AIRSPEED	400C	453T	.71M	453G

** WEAPON CONDITIONS ***

ERO SIGHT LINE AOA	39.4 MILS		
D.F.P.	371.9 MILS		
OTAL SIGHT SETTING	411.2 MILS		
RAB CROSSWIND CORRECTION	1.3 FT/KT		
RIFT CROSSWIND CORRECTION	29.7 FT/KT		2.2 MILS/KT
EAD/TAIL WIND CORRECTION	0.8 MILS/KT		
EAPON RANGE FIRST RELEASE	2.1NM	12849FT	3916M
LANT RANGE AT RELEASE	13787FT		
OMB TRAIL	0.1NM	586FT	179M
ME OF FALL FIRST RELEASE	17.59 SEC		
EAPON IMPACT ANGLE	38 DEG		
EAPON IMPACT VELOCITY	887 FT/SEC		

* SAFE ESCAPE SAFE SEPARATION DIVE RECOVERY INFORMATION ***

fe Escape not considered.

CAPE MANEUVER	Level Turn		
ATTACK HEADING (True/Mag)	45 / 32 DEG		
EGRESS HEADING (True/Mag)	360 / 347 DEG		
G/BANK	1.50 / 48		
ROLL RATE	30 DEG/SEC		
TURN RADIUS	2.7NM	16220FT	4944M
TURN LEFT 45 DEGREES			
ARING TGT TO AIRCRAFT AT WPN IMPACT	309T	295M	
X FRAGMENT TRAVEL			
ALTITUDE	2489A	4865M	
HORIZONTAL RANGE	2910FT		
TOF	26.7 SEC		

Figure B-7, Slow-High Level Planning

Profile Output Classification:
rofile 1
:\PFPS\data\attack\SPADS Dive.atk
4/04/05 15:30:28

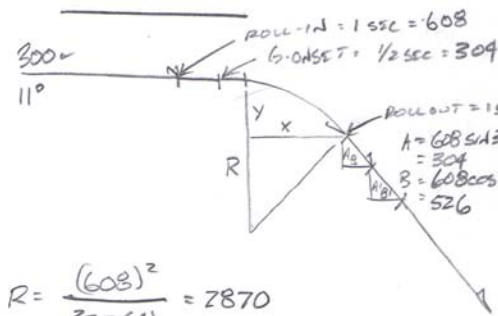
30° DIVE / 400

11°/300C = 360T = 608

ROLL-IN

** MISSION DATA ***

IRCRAFT	F16AB PW220	
ROSS WEIGHT	30000	
UNITION	BDU-50 LD	
USPENSION	TER-9/A	
ELIVERY	Dive	



15'' =

** TARGET DATA ***

ARGET DENSITY ALTITUDE	4251 FT		
ARGET ELEVATION	2376FT	724M	
ARGET TEMPERATURE	+27C	+80F	
ARGET ORIENTATION (Axis from North)	347M	360T	
ARGET DIMENSIONS:			
HEIGHT	25FT		
WIDTH	25FT		
DEPTH	25FT		
ARGET MIL SIZE AT WEAPON RELEASE	5.3 MILS		
ARGET MIL SIZE AT WEAPON IMPACT	8.5 MILS		

$R = \frac{(608)^2}{32.2(4)} = 2870$

$y = R(1-\cos 30) = 385$

$x = R \sin 30 = 1435$

RUN-IN ALT = 10172 + 304 + 385 = 10861

$A' = 11{,}000 - 10{,}861 = 139$

$B' = A'/\tan 30 = 241$

** RELEASE CONDITIONS ***

JMBER OF WEAPONS RELEASED	1			
ELEASE ALTITUDE FIRST WEAPON	5000A	7376M		
INIMUM RECOVERY CLEARANCE(AGL)	1500FT			
ELEASE ALTITUDE CORRECTED FOR ALT LAG		7449M		
ELEASE DIVE ANGLE	30.0 DEG			
ELEASE AIRSPEED	400C	453T	.71M	392G

ROLL-IN = 10767 + 241 + 526 + 1435 + 304 + 608
= 13881 = 2.3 NM

** TRACKING INFORMATION ***

IITIAL PIPPER PLACEMENT	38.4 MILS		
ERCENT DOWN BOMB FALL LINE FROM FPM	74.0		
IITIAL TARGET PLACEMENT	35.7 DEG		
IIT AIMOFF ANGLE(FLT PATH MKR TO TGT)	5.7 DEG		
ANT RANGE TO TARGET AT TRACK	13256FT		
IM-OFF DISTANCE	0.4NM	2627FT	801M
'ERAGE TRACK VELOCITY	683 FT/SEC		
INIMUM ATTACK PERIMETER	1.8NM	10767FT	3282M
ILL-OUT (TRACK) AIRSPEED	300C	357T	.56M
IA AT TRACK ALTITUDE	66.2 MILS		
ACK TIME	8 SEC		
ACK/MAP ALTITUDE	10109M	7733A	
ACK/MAP ALT CORRECTED FOR ALT LAG	10172M		

REL = 7^5
MRA = 5^4 @ 5° STEEP

* WEAPON CONDITIONS ***

LEVEL REL 11°/300 @ = 13564
300C = 360T = 608 ft/s

RO SIGHT LINE AOA	34.4 MILS		
D.F.P.	169.4 MILS		
TAL SIGHT SETTING	203.8 MILS		
IFT CROSSWIND CORRECTION	15.9 FT/KT		2.0 MILS/KT
AD/TAIL WIND CORRECTION	1.6 MILS/KT		
APON RANGE FIRST RELEASE	1.0NM	6033FT	1839M
ANT RANGE AT RELEASE	7836FT		
ME OF FALL FIRST RELEASE	9.44 SEC		
APON IMPACT ANGLE	47 DEG		
APON IMPACT VELOCITY	911 FT/SEC		

ROLL-IN 13881 = 0.5 SEC TREL

* SAFE ESCAPE SAFE SEPARATION DIVE RECOVERY INFORMATION ***
fe Escape not considered.

X FRAGMENT TRAVEL		
ALTITUDE	2489A	4865M
HORIZONTAL RANGE	2910FT	
TOF	26.7 SEC	
VE RECOVERY G	+4.0	
T LOST DURING DIVE RECOVERY	1220FT	
LEASE ALTITUDE FIRST WEAPON	5000A	7376M
N ALT DURING DIVE RECOVERY	3780A	6156M

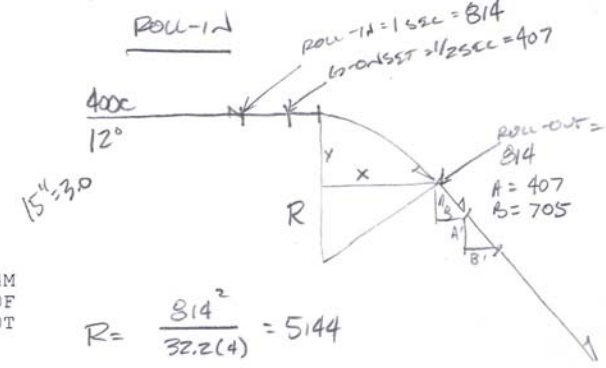
Figure B-8, Slow Dive Planning

Profile Output Classification:

30° DIVE /520

rofile 1
:\PFPS\data\attack\SPADS Dive.atk
4/04/05 15:30:01

12°/400c = 482T = 814



** MISSION DATA ***

IRCRAFT	F16AB PW220
ROSS WEIGHT	30000
UNITION	BDU-50 LD
USPENSION	TER-9/A
ELIVERY	Dive

** TARGET DATA ***

ARGET DENSITY ALTITUDE	4251 FT		
ARGET ELEVATION	2376FT	724M	
ARGET TEMPERATURE	+27C	+80F	
ARGET ORIENTATION (Axis from North)	347M	360T	
ARGET DIMENSIONS:			
HEIGHT	25FT		
WIDTH	25FT		
DEPTH	25FT		
ARGET MIL SIZE AT WEAPON RELEASE	5.0 MILS		
ARGET MIL SIZE AT WEAPON IMPACT	11.9 MILS		

$$R = \frac{814^2}{32.2(4)} = 5144$$

$$Y = R(1 - \cos 30) = 689$$

$$X = R \sin 30 = 2572$$

RUN-IN ALT = 11042 + 407 + 689 = 12138

** RELEASE CONDITIONS ***

$A' = -138$

$B' = -138/\tan 30 = -239$

UMBER OF WEAPONS RELEASED	1		
ELEASE ALTITUDE FIRST WEAPON	5000A	7376M	
INIMUM RECOVERY CLEARANCE(AGL)	1500FT		
ELEASE ALTITUDE CORRECTED FOR ALT LAG		7469M	
ELEASE DIVE ANGLE	30.0 DEG		
ELEASE AIRSPEED	520C	583T	.91M 505G

ROLL-IN RNG = 12836 - 239 + 705 + 2572 + 407 + 814 = 17095 = 2.8

** TRACKING INFORMATION ***

REL = 75
MRA = 63 @ 5° STEEP

NITIAL PIPPER PLACEMENT	44.1 MILS		
ERCENT DOWN BOMB FALL LINE FROM FPM	44.0		
NITIAL TARGET PLACEMENT	33.8 DEG		
NIT AIMOFF ANGLE(FLT PATH MKR TO TGT)	3.8 DEG		
LANT RANGE TO TARGET AT TRACK	15440FT		
IM-OFF DISTANCE	0.3NM	2024FT	617M
VERAGE TRACK VELOCITY	895 FT/SEC		
INIMUM ATTACK PERIMETER	2.1NM	12836FT	3912M
OLL-OUT (TRACK) AIRSPEED	400C	477T	.76M
OA AT TRACK ALTITUDE	34.1 MILS		
RACK TIME	8 SEC		
RACK/MAP ALTITUDE	10956M	8580A	
RACK/MAP ALT CORRECTED FOR ALT LAG	11042M		

LEVEL REL @ 12°/400 = 18864

400c = 482T = 814 ft/s

** WEAPON CONDITIONS ***

ERO SIGHT LINE AOA	20.9 MILS		
.D.F.P.	122.9 MILS		
OTAL SIGHT SETTING	143.8 MILS		
RIFT CROSSWIND CORRECTION	13.8 FT/KT		1.7 MILS/KT
EAD/TAIL WIND CORRECTION	1.2 MILS/KT		
EAPON RANGE FIRST RELEASE	1.1NM	6636FT	2023M
LANT RANGE AT RELEASE	8309FT		
IME OF FALL FIRST RELEASE	8.19 SEC		
EAPON IMPACT ANGLE	43 DEG		
EAPON IMPACT VELOCITY	1052 FT/SEC		

ROLL-IN 17095 = TREL + 2

** SAFE ESCAPE SAFE SEPARATION DIVE RECOVERY INFORMATION ***

ife Escape not considered.

AX FRAGMENT TRAVEL		
ALTITUDE	2489A	4865M
HORIZONTAL RANGE	2910FT	
TOF	26.7 SEC	
VE RECOVERY G	+4.0	
T LOST DURING DIVE RECOVERY	1841FT	
LEASE ALTITUDE FIRST WEAPON	5000A	7376M
N ALT DURING DIVE RECOVERY	3159A	5535M

Figure B-9, Fast Dive Planning

APPENDIX C: TEST POINT MATRICES

The following matrices were used for test point selection during the evaluation missions. The first matrix, Table C-1, shows the formation events used for part of the evaluation of the first test objective. The second matrix, Table C-2, shows the single-ship test points used for evaluation of the second test objective. The third matrix, Table C-3, illustrates the weapon delivery events used for evaluation of the first, third, and fourth test objectives.

Table C-1, Test/Chase Aircraft Maneuvers Used for Objective 1

Test Point	Start Position	Maneuver	Range	Conditions
1.1	Route	→ Fingertip → Route	< 5 nm	300 KCAS ≥5,000 ft AGL
1.2	Route	→ Fingertip → Route	> 10 nm	
1.3	Route	→ Fingertip → Cross-under / over	< 5 nm	
1.4	Route	→ Fingertip → Cross-under / over	> 10 nm	
1.5	Fingertip	180° turn	< 5 nm	
1.6	Fingertip	180° turn	> 10 nm	

Table C-2, Flight Test Points Used for Objective 2

Test Point	Slant Range	AGL Altitude	Flight path Angle to Radar	Airspeed
3.1	< 6 nm	< 1000 ft	<20°	400 KCAS
3.2	> 10 nm	< 1000 ft	<20°	400 KCAS
3.3	< 6 nm	> 5000 ft	<20°	400 KCAS
3.4	> 10 nm	> 5000 ft	<20°	400 KCAS
3.5	< 6 nm	< 1000 ft	>60°	400 KCAS
3.6	> 10 nm	< 1000 ft	>60°	400 KCAS
3.7	< 6 nm	> 5000 ft	>60°	400 KCAS
3.8	> 10 nm	> 5000 ft	>60°	400 KCAS
3.9	< 6 nm	< 1000 ft	<20°	550 KCAS
3.10	> 10 nm	< 1000 ft	<20°	550 KCAS
3.11	< 6 nm	> 5000 ft	<20°	550 KCAS
3.12	> 10 nm	> 5000 ft	<20°	550 KCAS
3.13	< 6 nm	< 1000 ft	>60°	550 KCAS
3.14	> 10 nm	< 1000 ft	>60°	550 KCAS
3.15	< 6 nm	> 5000 ft	>60°	550 KCAS
3.16	> 10 nm	> 5000 ft	>60°	550 KCAS

Table C-3, Munition Delivery Test Points Used for Objectives 1, 3 and 4

Test Point	Airspeed	Flightpath Angle to Radar	Altitude (AGL)	Delivery Type	Bomb Type	# of Bombs
2.1	400 KCAS	<20°	<1000 ft	Level	BDU-33	1
2.2	550 KCAS	<20°	<1000 ft	Level	BDU-33	1
2.3	400 KCAS	>60°	<1000 ft	Level	BDU-33	1
2.4	550 KCAS	>60°	<1000 ft	Level	BDU-33	1
2.5	400 KCAS	<20°	>5000 ft	Level	BDU-33	1
2.6	550 KCAS	<20°	>5000 ft	Level	BDU-33	1
2.7	400 KCAS	>60°	>5000 ft	Level	BDU-33	1
2.8	550 KCAS	>60°	>5000 ft	Level	BDU-33	1
2.9	400 KCAS	<20°	<1000 ft	Loft	BDU-33	1
2.10	550 KCAS	<20°	<1000 ft	Loft	BDU-33	1
2.11	400 KCAS	>60°	<1000 ft	Loft	BDU-33	1
2.12	550 KCAS	>60°	<1000 ft	Loft	BDU-33	1
2.13	400 KCAS	<20°	>5000 ft	Dive	BDU-33	1
2.14	550 KCAS	<20°	>5000 ft	Dive	BDU-33	1
2.15	400 KCAS	>60°	>5000 ft	Dive	BDU-33	1
2.16	550 KCAS	>60°	>5000 ft	Dive	BDU-33	1
2.17	400 KCAS	<20°	<1000 ft	Level	BDU-50	1
2.18	550 KCAS	<20°	<1000 ft	Level	BDU-50	1
2.19	400 KCAS	>60°	<1000 ft	Level	BDU-50	1
2.20	550 KCAS	>60°	<1000 ft	Level	BDU-50	1
2.21	400 KCAS	<20°	>5000 ft	Level	BDU-50	1
2.22	550 KCAS	<20°	>5000 ft	Level	BDU-50	1
2.23	400 KCAS	>60°	>5000 ft	Level	BDU-50	1
2.24	550 KCAS	>60°	>5000 ft	Level	BDU-50	1
2.25	400 KCAS	<20°	<1000 ft	Loft	BDU-50	1
2.26	550 KCAS	<20°	<1000 ft	Loft	BDU-50	1
2.27	400 KCAS	>60°	<1000 ft	Loft	BDU-50	1
2.28	550 KCAS	>60°	<1000 ft	Loft	BDU-50	1
2.29	400 KCAS	<20°	>5000 ft	Dive	BDU-50	1
2.30	550 KCAS	<20°	>5000 ft	Dive	BDU-50	1
2.31	400 KCAS	>60°	>5000 ft	Dive	BDU-50	1
2.32	550 KCAS	>60°	>5000 ft	Dive	BDU-50	1
2.33	400 KCAS	<20°	>5000 ft	Level	BDU-33	3
2.34	400 KCAS	>60°	>5000 ft	Level	BDU-33	3
2.35	400 KCAS	<20°	>5000 ft	Level	BDU-50	2
2.36	400 KCAS	>60°	>5000 ft	Level	BDU-50	2
2.37	400 KCAS	<20°	<1000 ft	Level	BDU-50	2
2.38	400 KCAS	>60°	<1000 ft	Level	BDU-50	2
2.39	400 KCAS	<20°	<1000 ft	Loft	BDU-50	2
2.40	400 KCAS	>60°	<1000 ft	Loft	BDU-50	2
2.41	400 KCAS	<20°	>5000 ft	Dive	BDU-50	2
2.42	400 KCAS	>60°	>5000 ft	Dive	BDU-50	2

APPENDIX D: TEST RESULTS

The TSPI error results for single ship tracking of Objective 2 are shown in Table D-1. In the table are the mean, standard deviation and median values for the slant range errors, radial velocity error, and elevation and azimuth angles.

Table D-1, Single-Ship Track Errors

Slant Range Error (feet)				*Radial Velocity Error (feet/sec)*			
Test Point	**Mean**	**Std Dev**	**Median**	**Test Point**	**Mean**	**Std Dev**	**Median**
3.1	-182	153	-281	3.1	-0.2	0.5	-0.1
3.2	9	11	11	3.2	0.3	0.4	0.2
3.3	34	11	35	3.3	0.1	0.4	0.1
3.4	25	8	25	3.4	0.3	0.2	0.3
3.5	-2	5	-3	3.5	-3.8	1.3	-3.7
3.6	-1	4	-1	3.6	2.2	1.0	2.2
3.7	17	7	16	3.7	-2.6	0.8	-2.5
3.8	NO RADAR RANGE DATA			3.8	1.7	0.8	1.5
3.9	1595	57	1612	3.9	-0.7	0.7	-0.6
3.10	12	9	13	3.10	0.0	0.4	-0.1
3.11	33	12	33	3.11	-0.3	0.4	-0.4
3.12	20	12	20	3.12	0.5	0.5	0.5
3.13	1055	753	1537	3.13	-3.3	1.3	-3.2
3.14	-2	4	-3	3.14	2.1	1.1	2.1
3.15	15	10	13	3.15	-3.6	1.2	-3.5
3.16	4	4	3	3.16	1.8	0.9	1.7
Elevation Angle Error (degs)				*Azimuth Angle Error (degs)*			
Test Point	**Mean**	**Std Dev**	**Median**	**Test Point**	**Mean**	**Std Dev**	**Median**
3.1	0.17	0.07	0.17	3.1	0.01	0.06	0.02
3.2	0.11	0.07	0.11	3.2	0.02	0.06	0.02
3.3	0.21	0.02	0.21	3.3	-0.04	0.06	0.004
3.4	0.14	0.03	0.14	3.4	0.02	0.02	0.03
3.5	0.23	0.06	0.22	3.5	-0.16	0.02	-0.16
3.6	0.09	0.11	0.08	3.6	0.04	0.05	0.04
3.7	0.27	0.02	0.27	3.7	-0.18	0.02	-0.17
3.8	0.14	0.06	0.14	3.8	0.03	0.05	0.03
3.9	0.23	0.09	0.23	3.9	-0.11	0.03	-0.11
3.10	0.12	0.06	0.12	3.10	0.03	0.04	0.04
3.11	0.21	0.04	0.22	3.11	-0.11	0.01	-0.12
3.12	0.15	0.03	0.15	3.12	0.04	0.03	0.04
3.13	0.24	0.04	0.25	3.13	-0.15	0.02	-0.15
3.14	0.09	0.15	0.10	3.14	0.06	0.11	0.05
3.15	0.24	0.02	0.24	3.15	-0.18	0.02	-0.17
3.16	0.16	0.03	0.16	3.16	0.04	0.03	0.04

The TSPI error results for bomb trajectory tracking of Objective 3 are shown in Table D-2. In the table are the mean, standard deviation and median values for the slant range errors, radial velocity error, and elevation and azimuth angles.

Table D-2, Bomb Trajectory Track Errors

Slant Range Error (feet)				***Radial Velocity Error (feet/sec)***			
Test Point	**Mean**	**St Dev**	**Median**	**Test Point**	**Mean**	**St Dev**	**Median**
2.17	NO DATA			2.17	NO DATA		
2.18				2.18			
2.19				2.19			
2.20	-2	45	1	2.20	-5.4	24.5	-1.7
2.21	-245	427	-3	2.21	-0.2	3.4	-0.2
2.22	-237	618	2	2.22	0.3	5.3	-0.6
2.23	NO DATA			2.23	NO DATA		
2.24	-30773	1569	-30680	2.24	39.0	14.3	34.6
2.25	-17	34	-9	2.25	-0.1	1.8	0.0
2.26	NO DATA			2.26	NO DATA		
2.27				2.27			
2.28				2.28			
2.29	-5	8	-4	2.29	-1.6	3.2	-1.1
2.30	-189	340	-9	2.30	-1.3	6.0	-2.1
2.31	9	4	10	2.31	5.5	4.3	6.7
2.32	10	5	11	2.32	4.3	3.8	4.5
Elevation Angle Error (degs)				***Azimuth Angle Error (degs)***			
Test Point	**Mean**	**St Dev**	**Median**	**Test Point**	**Mean**	**St Dev**	**Median**
2.17	NO DATA			2.17	NO DATA		
2.18				2.18			
2.19				2.19			
2.20	0.43	0.17	0.42	2.20	2.40	0.52	2.34
2.21	0.62	0.24	0.55	2.21	0.26	0.24	0.16
2.22	0.53	0.10	0.53	2.22	0.20	0.16	0.15
2.23	NO DATA			2.23	NO DATA		
2.24	-1.43	0.74	-1	2.24	3.56	0.68	3.81
2.25	0.52	0.04	0.52	2.25	0.18	0.03	0.17
2.26	NO DATA			2.26	NO DATA		
2.27				2.27			
2.28				2.28			
2.29	0.55	0.05	0.55	2.29	0.17	0.07	0.16
2.30	0.33	0.41	0.53	2.30	0.28	0.21	0.18
2.31	0.29	0.06	0.29	2.31	-0.10	0.03	-0.10
2.32	0.28	0.05	0.28	2.32	-0.10	0.03	-0.10

Table D-3 shows the results of the comparison between the SPADS predicted impact points and the VBS measured impacts. The data are presented in terms of predicted impact point bearing and distance as compared to the VBS truth source actual impact point for each delivery.

Table D-3, SPADS Impact Position Errors

Test Point	Distance (ft)	Bearing Angle (degrees)	NOTES
2.21	175.7	237.2	
2.22	2843.3	353.8	
2.29	172.8	256.0	
2.30	146.7	246.2	
2.23	70.0	190.7	
2.27	21.9	216.8	
2.28	15.1	227.0	
2.31	154.2	184.5	
2.32	71.2	181.5	
2.36	57.6	33.4	Ripple release of 2 bombs
2.36	21.3	295.3	
2.41	36.9	11.7	Ripple release of 2 bombs
2.41	32.8	299.5	

The track generation data taken for the first objective are shown in Table D-4. The table shows the number of tracks generated per object and the percentage of a bomb time of fall which was tracked by the radar.

Table D-4, Track Data for the Munition Tracking Test Point of Objective 1

Test Point	Tracks / Object	% of Bomb Fall Time Tracked
2.17	1	0.0
2.18	1.33	NO VBS DATA
2.19	0	0.0
2.20	1	100.0
2.21	1	72.3
2.22	0.67	97.1
2.23	0.67	77.0
2.24	1	60.9
2.25	0.67	92.0
2.26	DID NOT FLY	
2.27	1.67	87.1
2.28	1.33	90.8
2.29	0.67	79.0
2.30	1	74.8
2.31	1	78.4
2.32	1	72.8
2.35	0.75	NO VBS DATA
2.36	1	73.6
2.41	0.75	58.3

APPENDIX E: DOE ANALYSIS

Design of Experiments (DOE) statistical analysis was used as a way to mathematically formalize the interactions described in previous sections as well as to determine other interactions not readily observed in the data. These analyses were conducted with the assistance of Capt Bryon McClain (reference 7).

The process began with a description of each phase of the test. This included aircraft acquisition, aircraft tracking, bomb release, bomb trajectory tracking and bomb impact. At each of these phases of the test, factors that could affect the results were generated. Each of these factors was given a priority of high, medium or low depending on how large an effect it was expected to have on the results. Each of the variables was then assigned a category based on how the factor would be handled. It would either be a "variable" in which separate high and low values of the factor would be tested, a "control" which would be a definite value based on what the testers specified, a "log" where the value would be recorded and should stay constant for each test point but could not be controlled, or "noise" where no control or recording of the variable was possible and may not be constant during each test point. The factors considered are listed in Table E-1.

Table E-1, DOE Factors Considered

Factors	***Priority***	***Type***
Operator	HIGH	control
Transmitter Power	HIGH	control
Frequency	HIGH	control
Delivery Type	HIGH	variable
Number of Bombs	HIGH	variable
Bomb Type	HIGH	variable
Slant Range	HIGH	variable
Altitude	HIGH	variable
Aircraft Calibrated Airspeed	HIGH	variable
Flight Path Angle to Radar	HIGH	variable
Maneuver/Acceleration	MED	control
Humidity	LOW	noise
Sun Position (time of day)	LOW	control
Air Traffic in Background	MED	noise
Stores Configuration	LOW	log
Tail Number	LOW	log

After the factors were analyzed, each of the variables was assigned high and low values. These values were later used to determine the relationships between the variables and the time-space-position information (TSPI) errors. The variables and their associated high and low values are shown in Table E-2.

The test points derived for single aircraft tracking as well as munition deliveries are listed in Appendix C and the results are in Appendix D. Unfortunately, not enough test points were completed to conduct a DOE analysis on the munition delivery data. However, the data from the single aircraft tracking was complete except for the slant range data for test point 3.8, allowing a DOE analysis. In the following plots, the four factors applicable to the single aircraft tracking are (A) slant range, (B) elevation, (C) flight path angle and (D) airspeed.

Table E-2, High and Low Values for each of the DOE Variables

Variable	***Low Value***	***High Value***
Slant Range	< 6 nm	> 10 nm
Altitude	< 1000 ft AGL	> 5000 ft AGL
Flight Path Angle to Radar (Precision Bomb Site)	< 20° (PB-10)	> 60° (PB-1)
Aircraft Calibrated Airspeed	400 KCAS	550 KCAS
Bomb Type	BDU-33	BDU-50
Delivery Type	Level	Loft / Dive
Number of Bombs	1	2 (BDU-50) 3 (BDU-33)

Figure E-1 is an interaction plot showing the effects of the different factors' high and low values on the slant range error. The means of the errors are plotted with error bars showing 95% confidence intervals. Slant range errors were shown to be affected by the range, altitude and airspeed factors. At low altitudes, high speeds and close range, the range error was very large. This was due to the error of test points 3.1, 3.9 and 3.13 being one to two orders of magnitude higher than the other test points. It is not known what caused these errors.

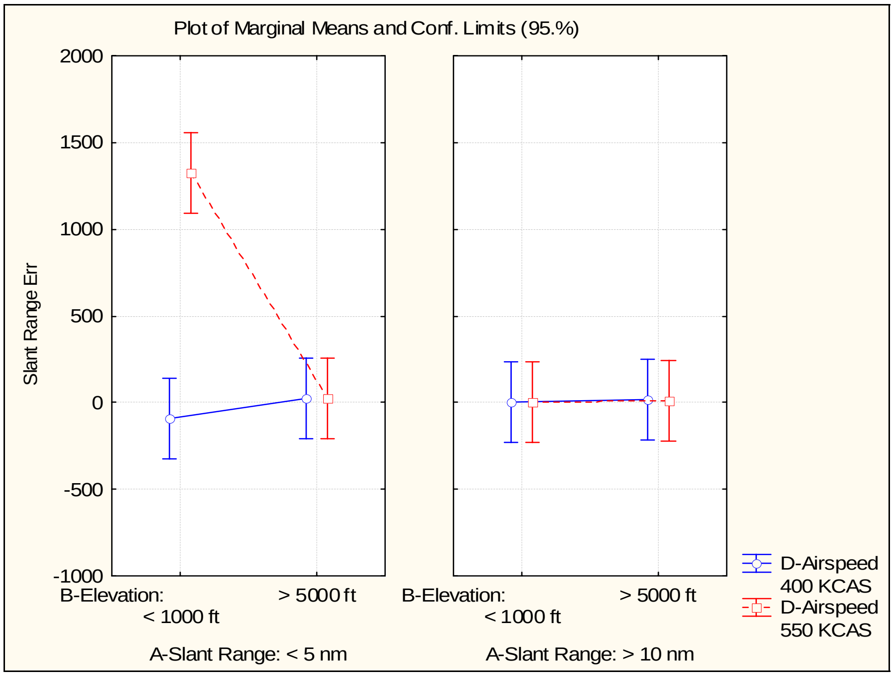


Figure E-1, DOE Interaction Plot for the Slant Range Error

The radial velocity was shown to have higher errors when the flight path angle to the radar was high, or when the aircraft was flying through the "notch", as shown in Figure E-2. The velocity errors were lowest at the 9-10 nautical mile slant range.

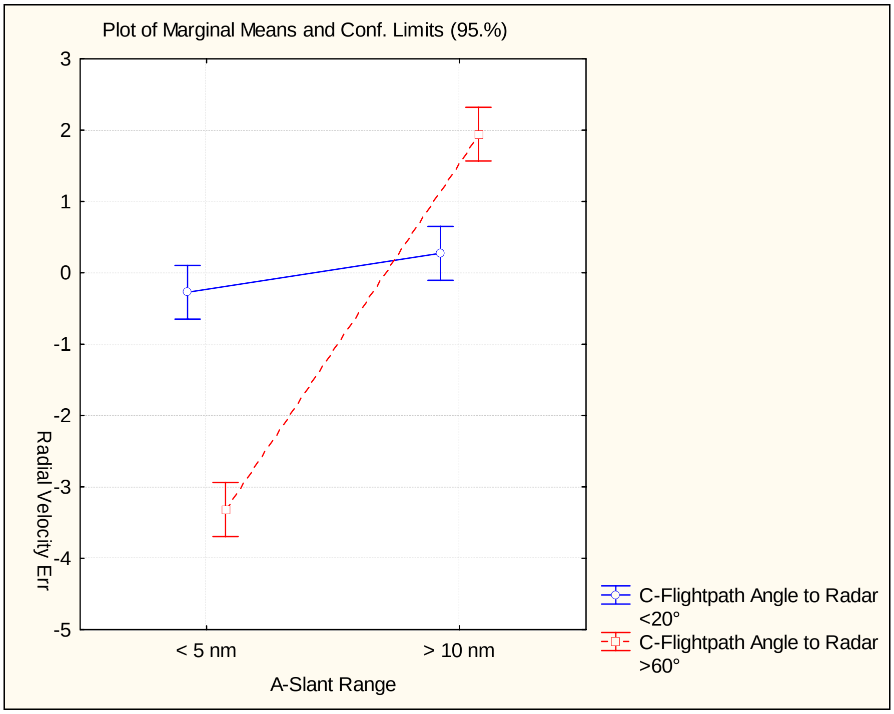


Figure E-2, Radial Velocity Error Dependence upon Flightpath Angle

For the azimuth angle, the DOE analysis showed that the errors were large when the range was small, the flight path angle to the radar was large, and the speed was high, as shown in Figure E-3. These conditions correspond to occasions when the rates of change of the angle and airspeeds were high which agreed with the results previously shown. The smallest errors occurred at medium range (9-10 nautical miles) with the aircraft flying towards the radar at lower speeds, which were the conditions at which the lowest angular rates were encountered.

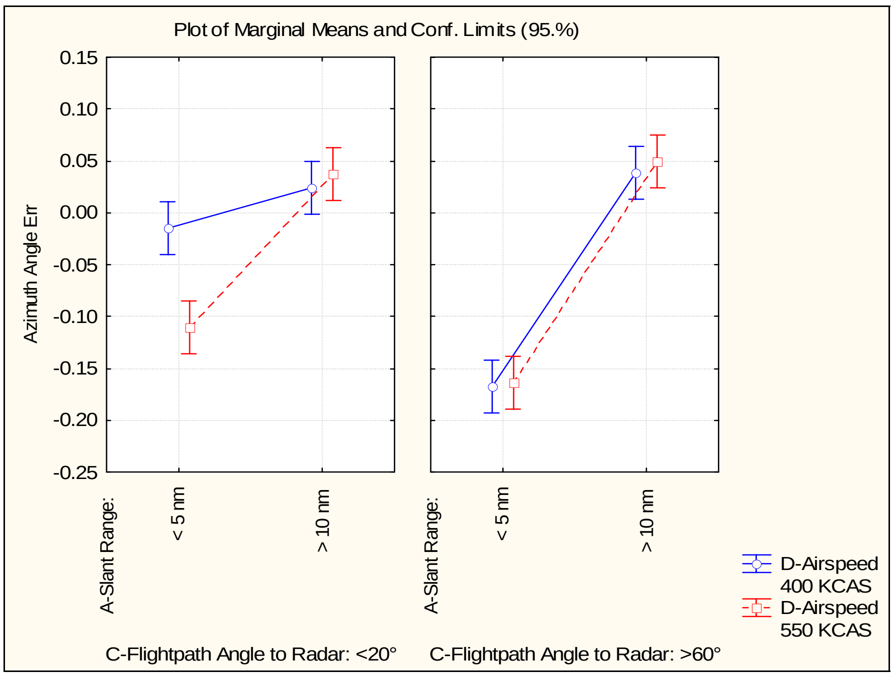


Figure E-3, Aziumth Angle Error Dependence upon the DOE Factors

The elevation angle error was shown to depend on slant range and elevation. Errors were higher when the slant range was low, as shown in Figure E-4, and when the elevation was high. High altitudes and short ranges correspond to high elevation angles. This analysis agreed with Figure 9, where it was shown that the elevation angle error increased with increasing elevation angle.

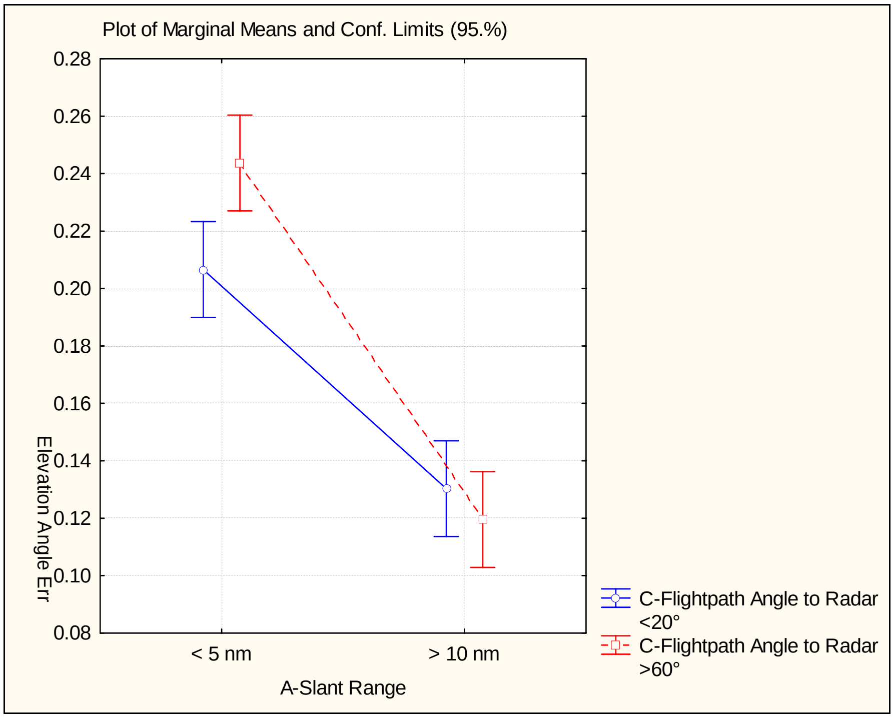


Figure E-4, Elevation Angle Error Dependence upon the DOE Factors

Overall, the following conclusions from the DOE analysis were made. First, the factors that had the greatest effect upon the variable errors (in order of precedence) were slant range from target to radar, flight path angle to radar, and elevation. Second, there were other interactions between factors that had an effect on the errors. These two-way interactions (in order of precedence) were slant range with flight path angle to radar, slant range with elevation and airspeed interacts with all other factors (but is not a factor by itself). Lastly, the radar had a very definite set of conditions where the errors were the smallest. This occurred when the slant range was around 10 nautical miles, the flight path angle to the radar was less than 20 degrees and the target aircraft's altitude was around 1000 feet. It was also determined that when these values are not set, a low airspeed is required to achieve low errors.

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APPENDIX F: LIST OF ABBREVIATIONS AND SYMBOLS

AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AGL	Above Ground Level
ARDS	Advanced Range Data System
CCIP	Continuously-Computed Impact Point
CCRP	Continuously-Computed Release Point
Cine-T	Cinetheodolite
CP	Contact Point
CW	Continuous Wave
CWDS	Combat Weapon Delivery Software
dB	Decibel
DBS	Doppler Beam Sharpening
DOE	Design of Experiments
FFT	Fast Fourier Transform
GPS	Global Positioning System
HPA	High Power Amplifiers
HSI	Horizontal Situation Indicator
HUD	Heads Up Display
INS	Inertial Navigation System
IP	Instructor Pilot, Initial Point
JON	Job Order Number
KCAS	Knots Calibrated Airspeed
KTM	Kineto Tracking Mount
MFCW	Multi-Frequency Continuous Wave
MOA	Military Operating Area
MOT	Multi-Object Tracking
MSL	Mean Sea Level
nm	Nautical Miles
SCP	Stores Control Panel
SLAP	Solar and Lunar Almanac Predictions
SPADS	Spaceport Arrival and Departure System

SUU	Suspension Unit
TECCS	Test Evaluation Command and Control System
TOF	Time of Fall
TER	Triple Ejector Rack
TIM	Technical Information Memorandum
TSPI	Time-Space-Position Information
VBS	Video Bomb Scoring

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